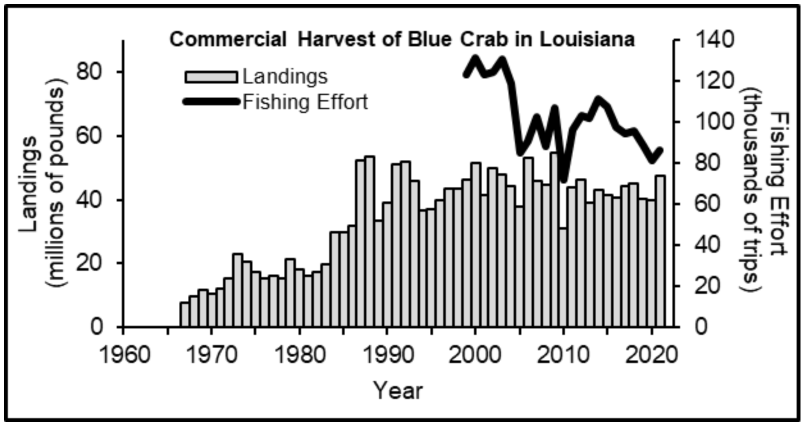
Update Assessment of Blue Crab in Louisiana Waters
2022 Report

Executive Summary

- Based on results of this assessment update, the Louisiana blue crab stock is currently not overfished or exceeding the exploitable biomass target, but was considered overfished in 1995, 2013, and 2015. Further, the stock is currently not experiencing overfishing or exceeding the fishing mortality target.
- Commercial landings of blue crab in Louisiana have remained above 40 million pounds per year since 1997 with the exception of 2005, 2010, and 2013. The highest reported landings were 53.7 and 55.0 million pounds harvested in 1988 and 2009, respectively.



- This assessment update is based on a Collie-Sissenwine or catch-survey analysis and results in estimates of exploitable biomass and recruitment of the Louisiana blue crab stock, 1968-2021. Annual fishing mortality is estimated, but is not available for the last year of the time-series. This assessment model has been extensively used in crustacean stock assessments. Data requirements include a time-series of observed landings and corresponding abundance indices for juvenile and exploitable life stages. Indices of abundance are derived from the Louisiana Department of Wildlife and Fisheries fishery-independent marine inshore trawl survey. Landings are taken from National Marine Fisheries Service statistical records, 1968-1998, and the Louisiana Department of Wildlife and Fisheries Trip Ticket Program, 1999-2021.
- In an earlier assessment (West et al. 2011), explicit limits and targets of fishing were proposed as conservation standards to ensure sustainability of the Louisiana blue crab resource. The Louisiana Wildlife and Fisheries Commission adopted a resolution on February 6, 2014 establishing the following policy based on the proposed limits and targets of fishing: "Should the fishing mortality or exploitable biomass exceed the overfished or overfishing limits, or exceed the targets for three consecutive years, as defined in the most current Louisiana blue crab stock assessment, LDWF shall come before the Commission with an updated assessment and a series of management options for the Commission to review and act upon, intended to keep the fishery from becoming overfished, and that management options for review and action shall include provisions for emergency closures, time based closures, and spatial closures."
- In the 2016 assessment update (West et al. 2016), the Louisiana blue crab stock was identified as overfished. Based on that status, the Louisiana Legislature and the Wildlife and Fisheries Commission took actions to reduce harvest. Management actions included: legislation to expand crab trap cleanup abilities, commission rule to ban harvest of immature females, allow a seasonal closure of all crab harvest in 2017, and allow seasonal closures of female crab harvest in 2018 and 2019. This

assessment is the second assessment update intended to explore the response of the blue crab stock to recent environmental conditions and the effectiveness of those management actions enacted.

Summary of Changes from Previous Assessment

- Assessment model inputs have been updated through 2021. No changes have been made to the assessment model itself. A time-series of blue crab stock removals from the incidental blue crab catches from the Louisiana inshore shrimp fishery are estimated and included in the landings input of the assessment model in this stock assessment update.

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1. Introduction

A catch-survey or Collie-Sissenwine analysis (Collie and Sissenwine, 1983) is applied to the Louisiana (LA) blue crab *Callinectes sapidus* stock. This model balances the number of individuals from one life stage to the next (i.e., juveniles to exploitable sizes) given constant natural mortality, while scaling these values to harvest. Data requirements are a time-series of observed landings and corresponding abundance indices for juvenile and adult life stages. Indices of abundance are derived from the Louisiana Department of Wildlife and Fisheries (LDWF) fishery-independent 16-foot marine inshore trawl survey. Landings are taken from National Marine Fisheries Service (NMFS) statistical records, 1968-1998, and the LDWF Trip Ticket Program, 1999-2021.

1.1 Regulations

The Louisiana blue crab fishery and its industry are governed by the Louisiana State Legislature, the Wildlife and Fisheries Commission, and the Department of Wildlife and Fisheries. The Louisiana commercial blue crab fishery is currently regulated with a minimum size limit (i.e., a minimum carapace width of 5 inches) in addition to gear restrictions. Recreationally caught blue crabs are not subject to a minimum size limit but are limited to twelve dozen crabs per recreational fisher. No bag and possession limits exist for the commercial fishery.

In the 2016 assessment update (West et al., 2016), the Louisiana blue crab stock was identified as overfished. Based on that status, the Louisiana Legislature and the Wildlife and Fisheries Commission took actions to reduce harvest as described below.

Regulations were enacted by the Wildlife and Fisheries Commission protecting commercially landed immature female blue crabs from harvest provisionally from 2017 through 2019 except when in a pre-molt stage being held for processing as a soft-shell crab. During the 2019 Legislative Regular Session, the prohibition on the commercial harvest of immature female blue crabs was made permanent. Additional regulations were also enacted for a seasonal closure of all crab harvest in 2017 (30-day period beginning on 3rd Monday in February) and seasonal closures of all commercially landed female crab harvest in 2018 (March 1st through April 30th) and 2019 (September 9th through October 13th).

Legislation that become effective November 2017 modified escape ring requirements where each crab trap must now have a minimum of three escape rings that are 2-3/8 inches in inside diameter or larger. Legislation enacted in 2016 expanded crab trap cleanup abilities where at any time crab harvest is closed for biological or technical reasons, the Wildlife and Fisheries Commission may prohibit the usage of crab traps for the duration of the closure. Additional legislation was enacted in 2018 allowing the Wildlife and Fisheries Commission to determine the disposition of abandoned crab traps removed from a closed area. This modification will allow future programs to be established, such as trap recycling or buyback programs.

1.2 Trends in Harvest

Trends in harvest were reviewed in the earlier assessment report (West et al. 2011). The time-series of annual LA commercial hard crab landings used in this assessment (1968-2021) is presented (Table 1, Figure 1).

2. Data Sources

2.1 Fishery Dependent

Commercial Landings

Louisiana blue crab commercial harvest is derived from NMFS statistical records, 1968-1998, and the LDWF Trip Ticket program, 1999-2021 (Table 1, Figure 1).

Recreational Landings

A time-series of recreational harvest records currently does not exist. Guillory (1999b) estimates the recreational harvest rate as 4.1% of the reported commercial harvest in a survey of the recreational blue crab fishery in Terrebonne Parish, LA. For assessment modeling purposes, a recreational time-series of blue crab landings is calculated by expanding annual commercial landings as individuals by 5% (see *4. Assessment Model*).

Shrimp Fishery Bycatch

Bycatch has been characterized for the 2019-2020 inshore LA shrimp fishery (Cagle and West 2020; see *Appendix 1*). Incidental catches of blue crab were observed in this study. Incidental catches of blue crab were not observed in the most recent bycatch study from the offshore GOM shrimp fishery (Scott-Denton et al. 2012).

A time-series of annual LA inshore shrimp fishery bycatch of blue crab in units of weight is estimated for assessment modeling purposes as the product of the mean bycatch to shrimp sample ratio from the recent bycatch study, the annual inshore LA shrimp landings in units of weight, and the proportion of blue crab in terms of weight observed in the catches of the bycatch study (Table 2), under the assumption that estimates from the study are characteristic of the inshore shrimp fishery through time. While this assumption allows calculation of a bycatch time-series, the fishery has transformed and developed over time making this assumption unlikely. Nevertheless, a time-series of blue crab bycatch estimates are calculated following the method outlined.

Louisiana commercial inshore shrimp harvest is derived from NMFS statistical records, 1977-1998, and the LDWF Trip Ticket program, 1999-2021. Louisiana annual inshore shrimp harvests are not available pre-1977 and are therefore calculated from the product of the ratio of mean LA inshore shrimp landings (1977-1979) to mean LA total (inshore+offshore) shrimp landings (1977-1979) and the total annual LA shrimp landings from 1968-1976. Further, total LA shrimp landings are not available from 1972-1976 and are therefore calculated as the average total LA shrimp landings from1971 and 1977.

Annual bycatch estimates in units of weight are converted to numbers (Table 2) using the observed mean weight of blue crabs in the bycatch study. Blue crab bycatch estimates are further delineated as live or dead bycatch using the discard mortality rate reported for blue crab bycatch of the North Carolina inshore shrimp fishery (36%) by Logothetis and McCuiston (2006). Due to the resilience of blue crab released from salt boxes (Colura et al. 2001, Haddad 2019), higher discard mortality rates of the LA inshore shrimp fishery blue crab bycatch are not considered in this assessment. The time-series of estimated dead blue crab bycatch from the LA inshore shrimp fishery, as numbers of crabs, are included as an input of the assessment model (see *4. Assessment Model*).

2.2 Fishery Independent

Blue crab abundance indices are derived from the LDWF fishery-independent marine inshore 16-foot trawl survey. This survey is primarily used to sample penaeid shrimp, blue crabs, and bottomfish in inshore bays and lakes. Sampling gear is a 4.9m flat otter trawl with a body and cod-end consisting of 19mm and 6.4mm bar meshes, respectively. Samples are 10 minute tows. All captured crabs are enumerated and a maximum of 50 randomly selected crabs per sample are measured (in 5mm CW bins). When more than 50 crabs are captured, catch-at-size is derived as the product of total catch and proportional subsample-at-size.

The survey has been conducted from 1967 to present at fixed sampling locations. In October of 2010, additional fixed sampling locations were added to this survey. To alleviate time-series bias associated with addition of these new stations, relative abundance time-series used in this assessment are constructed by retaining only the long-term stations for analysis.

Abundance indices are developed for life stages relative to the fishery (Table 3). These include: 1) adult or exploitable crabs (i.e., $\geq$125mm CW), 2) juveniles or crabs that will recruit to the fishery during the survey year (i.e., by December 31st), and 3) young-of-the year or crabs that will not recruit to the fishery during the survey year (Table 3). Due to size selectivity of the survey gear, crabs <25mm CW are excluded from index development. Crabs that will not recruit to the fishery during the survey year are identified by seasonal growth functions (see *Growth* section).

Mean catch-per-tow and its variance are calculated by assuming a delta-lognormal distribution. This method is appropriate for log-normally distributed survey datasets when a proportion of zero catches occur (Pennington, 1983; Pennington, 1996). In this case, the means are the product of the proportion of positive catches (assuming a binomial error structure) and the geometric mean catch-per-unit effort of successful trips (assuming a lognormal error structure). Its variance is approximated as:

$$Var(XY) \approx \mu_Y^2\sigma_X^2 + \mu_X^2\sigma_Y^2 + 2\mu_X\mu_Y\rho\sigma_X\sigma_Y \quad [1]$$

where μ_Y is the binomial mean proportion of positive catches, μ_X is the geometric mean catch-per-unit-effort of successful tows, σ_Y^2 and σ_X^2 are the respective variances, and ρ is the correlation between X and Y.

3. Life History Information

Guillory et al. (1996) summarized literature and data on the biology and ecology of blue crabs in a source document for the management of the Louisiana blue crab fishery. In addition to describing the fishery and commenting on research needs, the authors described blue crab taxonomy and nomenclature; larval, juvenile and adult morphology; distribution and abundance; habitat utilization; reproduction; age and growth; trophic relationships; behavior; movement and migration; pathology and parasitology; environmental tolerances; recruitment mechanisms; and mortality. This document was revised and updated in 2014 and again in 2022 (Bourgeois et al. 2014, and Cagle and Isaacs 2022).

In “The Blue Crab Fishery of the Gulf of Mexico, United States: A Regional Management Plan”, Guillory et al. (2001) developed a broad and comprehensive document addressing all relevant aspects of blue crab biology and the fishery. In addition to describing stock habitat, fishery management jurisdiction, economic and sociocultural characteristics of the fishery, management considerations/recommendations, and research needs, the authors provided detailed information on blue crab life history, including: geographic distribution; classification, morphology and genetic characterization; age, growth and maturation; reproduction; stock-recruitment relationship; larval development, distribution and abundance; megalopal settlement and recruitment; juvenile development, distribution and abundance; seasonal and areal distribution; factors influencing survival; parasites and diseases; food habits; predator/prey relationships; interspecific and intraspecific predation; foraging behavior; larval, juvenile and adult behavior; autonomy; and movements/migrations. This document was updated in 2015 by the Blue Crab Technical Task Force of the Gulf States Marine Fisheries Commission.

3.1 Unit Stock Definition

Adult blue crabs in the northern Gulf of Mexico (GOM) generally remain within one estuary for life. Females, however, migrate to higher salinity nearshore waters to spawn, where larvae are then dispersed offshore via tidal transport (Guillory et al. 2001). Recruitment and settlement of larvae into northern GOM estuaries as megalopae is likely influenced by wind and tidal circulation processes (Perry et al. 1995). Stock mixing between estuaries (and states) is very probable given these larval transport mechanisms. Nonetheless, blue crab landings from the northern Gulf of Mexico (GOM) are primarily of Louisiana origin.

For purposes of this assessment the blue crab unit stock is defined as those crabs occurring in LA waters. This approach is consistent with the current non-regional or statewide management strategy.

3.2 Maturity

Carapace width (CW) at maturity is reported by Guillory and Hein (1997a) for blue crabs from the Terrebonne Basin, LA. Males and females reached 50% sexual maturity at 110mm and 125mm CW, respectively. The CW-at-50% sexual maturity for female crabs corresponds with the minimum size limit of the LA commercial blue crab fishery (i.e., 127mm CW). Males and females reached 100% sexual maturity at 130mm and 160mm CW, respectively.

3.3 Growth

Blue crabs exhibit a discontinuous growth pattern; where growth occurs during the molting process (Guillory et al., 2001). Continuous growth models, however, are used to describe blue crab growth (Helser and Kahn, 2001; Pellegrin et al., 2001; Rugolo et al., 1998; Smith, 1997). In this assessment, Gompertz growth functions developed in the earlier LDWF crab assessment (West et al. 2011) are used to describe LA blue crab growth. The Gompertz model is configured as:

$$CW_t = CW_\infty e^{\alpha(e^{\beta t})} \quad [2]$$

where CW_t is CW-at-age, CW_∞ is the asymptotic average maximum CW, and α and β are constant growth coefficients. The seasonal and non-seasonal parameter estimates are presented in Table 4.

A monthly size-at-capture table is developed from the seasonal growth functions (Table 5) to identify crabs that will not recruit to the fishery during the survey year (i.e., by December 31st). This table represents CW-at-capture of monthly crab cohorts and implies variation in CW-at-age is primarily due to time of hatching. Carapace widths of crabs not fully-recruited to the trawl gear (i.e., < 25mm CW) are excluded. Rows represent monthly cohorts (or seasonal growth trajectories), with the current year-class above the diagonal and the previous year-class below the diagonal. Columns represent months of the LDWF fishery independent trawl survey. As an example, blue crabs captured by the trawl survey in August that are ≤63mm CW (or the current year's March-August cohorts) are considered young-of-the year crabs. An obvious discrepancy exists for the survey month of June, where the previous years' December cohort is approximately the same size as the current years' March cohort. To account for this, young-of-the-year crabs are only identified from July-December captures.

3.4 Morphometrics

Carapace width-weight regressions were developed by Guillory and Hein (1997a) for blue crabs from the Terrebonne Basin, LA. For the purpose of this assessment, only the pooled (or non-sex specific) model is used. Blue crab weight at CW is calculated from:

$$W = 8.26 \times 10^{-4} CW^{2.446} \quad [3]$$

where W is weight in grams and CW is carapace width in mm.

3.5 Natural Mortality

Due to the difficulty of directly estimating instantaneous natural mortality (M) of blue crab, M is estimated based on assumptions of maximum age and the proportion of the stock surviving to the maximum age (Quinn and Deriso, 1999). Reported maximum age of blue crab along the Atlantic Coast range from 3-6 years (Kahn and Helser, 2005; Miller et al., 2005; Murphy et al., 2007). There are no longevity estimates for blue crab in the GOM (Guillory et al., 2001). Instantaneous natural mortality in this assessment is estimated as M=1.0, based on the assumption that approximately 5% of the stock remains alive to 3 years of age.

3.6 Relative Productivity/Resilience

Productivity is a function of fecundity, growth rates, natural mortality, age of maturity, and longevity and can be a reasonable proxy for resilience. We characterize the relative productivity of GOM blue crab based on life-history characteristics, following methods described in SEDAR 9 (SEDAR, 2006), with a classification scheme developed at the FAO second technical consultation on the suitability of the CITES criteria for listing commercially-exploited aquatic species (FAO 2001; Table 6). Each life history characteristic (von Bertalanffy growth rate, age at maturity, longevity, and natural mortality rate) was assigned a rank (low=1, medium=2, and high=3) and then averaged to compute an overall productivity score. Parameter estimates are taken from West et al. (2011) and VanderKooy (2013). In this case, the overall productivity score is 3.0 for GOM blue crab indicating high productivity and resilience.

4. Assessment Model

A catch-survey (CS) or Collie-Sissenwine analysis (Collie and Sissenwine, 1983) is used in this assessment to describe the dynamics of the LA blue crab stock. The CS modeling approach is intended for data moderate situations where a full age structure is lacking. Model requirements include: 1) annual abundance indices for juvenile and adult life stages, 2) annual landings estimates as individuals, 3) an estimate of instantaneous natural mortality, and 4) the relative selectivity of the juvenile and adult life stages to the survey gear.

4.1 Catch-Survey Model Configuration

The CS model is based on the modified Delury discrete difference equation (Collie and Sissenwine, 1983):

$$N_{y+1} = (N_y + R_y - C_y)e^{-M} \quad [4]$$

where y is the fishing and survey year (i.e., January 1st through December 31st), N_y is the abundance of adult crabs in that year, N_{y+1} is the abundance of adult crabs in the following year, R_y is the abundance of juveniles, C_y is harvest as individuals and is the sum of the landings of the individual fleets (commercial, recreational, and dead bycatch), and M is the constant natural mortality rate. To approximate landings occurring throughout the year, the model equation is reconfigured as:

$$N_{y+1} = \left[\left(N_y + R_y\right)e^{-0.50M} - C_y\right]e^{-0.50M} \quad [5]$$

where juvenile and adult crabs are reduced by a half year of natural mortality before the catch is removed. Remaining survivors from the fishery are then reduced by another half year of natural mortality.

Survey indices of abundance are scaled to absolute abundance as:

$$n_y = q_n N_y e^{\eta_y} \text{ and } r_y = q_r R_y e^{\delta_y} \quad [6, 7]$$

where r_y and n_y are the observed abundance indices of juvenile and adult blue crabs, q_r and q_n are the respective catchabilities of the survey gear for juvenile and adult crabs, and e^{δ_y} and e^{η_y} are the log-normally distributed observation errors for the juvenile and adult abundance indices. Reconfiguring the model equation by substituting abundance indices for absolute abundance and incorporating lognormal process error e^{ε_y} yields:

$$n_{y+1} = \left[\left(n_y + \frac{r_y}{s_r}\right)e^{-0.50M} - q_n C_y\right]e^{-0.50M}e^{\varepsilon_y} \quad [8]$$

where $s_r = \frac{q_r}{q_n}$ is the relative selectivity of juveniles to adult crabs in the sampling gear. Log-normal process error e^{ε_y} is taken as the difference between n_y calculated from equations [6] and [8]. Equation [8] is solved iteratively by minimizing the following objective function:

$$SSQ(\Theta_{CS}) = \lambda_\varepsilon \sum_{y=2}^{Y} \varepsilon_y^2 + \sum_{y=1}^{Y} \eta_y^2 + \lambda_\delta \sum_{y=1}^{Y-1} \delta_y^2$$
[9]

where Θ_{CS} is the parameter vector and λ_ε and λ_δ are user-defined weights of the process and juvenile observation error relative to the adult observation error. Thus, $2Y$ parameters are estimated: n_y for all years, r_y for all years except the terminal year, and q_n. Given these estimates, absolute abundances are estimated from the following:

$$R_y = \frac{\hat{r}_y}{s_r \hat{q}_n} \text{ and } N_y = \frac{\hat{n}_y}{\hat{q}_n} \quad [10, 11]$$

where $\hat{r}_y$ and $\hat{n}_y$ are the model estimated abundance indices of juvenile and adult crabs, respectively, and $\hat{q}_n$ is the model estimated catchability of adult crabs to the survey gear. Recruit abundance is estimated in the terminal year by using observed r_y.

4.2 Fishing Mortality Estimation

Annual estimates of instantaneous total mortality are derived from the following survival ratio:

$$Z_y = log_e\left[\frac{N_y + R_y}{N_{y+1}}\right] \quad [12]$$

Estimating annual instantaneous fishing mortality F_y from $Z_y - M$ would include R_y (or crabs not available to the fishery) into the fishing mortality calculation. Because harvest occurs concurrently with M in this fishery (i.e., type II fishery; Ricker, 1975) and to avoid additional bias from $F_y = Z_y - M$, we estimate annual fleet-specific (commercial, recreational, and dead bycatch) fishing mortality F_{yf} from the following rearrangement of Baranov's catch equation:

$$F_{yf} = \frac{u_{yf} Z_y}{1 - e^{-Z_y}} \quad [13]$$

where annual fleet-specific exploitation is estimated as:

$$u_{yf} = \left[\frac{C_{yf}}{(R_y + N_y)}\right] \quad [14]$$

Total annual fishing mortality and annual exploitation rates are calculated by summing the fleet-specific estimates.

4.3 Biomass Conversions

Annual size distributions of Louisiana blue crab landings currently do not exist. Due to this lack of fishery dependent information, annual size distributions of blue crab captured from the LDWF FI 16-foot marine inshore trawl survey are used as proxies to describe the annual size compositions of blue crab directed landings (see *Research and Data Needs*).

Annual commercial landings in biomass are converted to individuals as:

$$C_y = H_y / \overline{W}_{y,\geq 125mm} \quad [15]$$

where C_y is annual harvest as individuals, H_y is annual harvest as biomass, and $\overline{W}_{y,\geq 125mm}$ are annual mean weights of adult blue crab catches derived from the LDWF FI 16-foot marine inshore trawl survey (Table 8). Blue crab bycatch in biomass is converted to individuals as described above with the mean weight of blue crab bycatch from the recent bycatch study substituted (see *Shrimp Fishery Bycatch*).

Model estimated abundance is converted to biomass as:

$$B_y = R_y \overline{W}_{y,<125mm} + N_y \overline{W}_{y,\geq 125mm} \quad [16]$$

where B_y is total annual biomass, R_y and N_y are model estimated annual abundances of juvenile and adult crabs, and $\overline{W}_{y,<125mm}$ and $\overline{W}_{y,\geq 125mm}$ are annual mean weights of juvenile and adult blue crab catches derived from the LDWF FI 16-foot marine inshore trawl survey (Table 7).

4.4 Model Inputs / Assumptions

Catch-survey model assumptions are: 1) the stock is closed to migration, 2) natural mortality occurs at a constant rate, and 3) all surviving recruits will grow into the fully-recruited stage within the model year. Survey indices of abundance are assumed proportional to absolute abundance. Crabs greater than 25mm CW are assumed equally vulnerable to the survey gear implying s_r=1.0. Relative weights λ_ε and λ_δ are fixed as 1.0 in this assessment.

Louisiana blue crab harvest is derived from commercial hard crab landings, which include: NMFS statistical records, 1968-1998, and the LDWF Trip Ticket Program, 1999-2021 (Table 1). Commercial hard crab landings as individuals are expanded by 5% to approximate for recreational harvest. This rate is consistent with Guillory's (1999b) survey of the recreational blue crab fishery in Terrebonne Parish, LA. A time-series of dead blue crab bycatch from the LA inshore shrimp fishery (Table 2) is also included in the annual landings of the assessment model.

Through simulation analysis, Mesnil (2003) demonstrates how staging error (i.e., analogous to aging error in a VPA) can bias estimates of absolute abundance and recommends "carefully allocating members to either stage". Individuals that will not recruit to the fishery during the survey year are accounted for by reconfiguring r_y as the sum of the young-of-the-year index in year and the juvenile index in year+1 (Table 8). This creates an index where all surviving recruits will recruit to legal-size within the survey year.

4.5 Model Results

The assessment model provides reasonable fits to the adult and juvenile abundance indices (Figures 2-4); however, patterning of the residuals is apparent in the more recent years of the time-series where model predictions of adult relative abundance are consistently underestimated and model predictions of juvenile relative abundance are consistently overestimated. The juvenile index suggests a considerable decline over the latter half of the time-series examined. The assessment model tracks this decline, but underestimates its magnitude suggesting additional processes aren't captured by the assessment model (e.g. temporal, spatial, and/or environmental; see *Research and Data Needs* Section).

The catchability coefficient is estimated as $\hat{q}_n$ =0.00372 in this assessment. Annual exploitable (adult) biomass estimates range from 20 to 118 million pounds (Table 9, Figure 5). Exploitable biomass estimates generally decline after 1990, where estimates from earlier years were rarely below 60 million pounds. Increases in exploitation during the 1990s coincide with this decline (Figure 6). A large population response is evident in the years following the passages of Hurricane Katrina and Rita which caused a substantial reduction in the directed effort and supporting infrastructure of the Louisiana commercial blue crab fleet. These storms also provided optimum environmental conditions for settlement of megalopae and young crabs into Louisiana estuaries via storm surge and likely enhanced recruitment. The 2021 exploitable biomass estimate is 63 million pounds and is the highest exploitable biomass observed since 2006.

Juvenile abundance estimates range from 230 to 733 million individuals (Table 9, Figure 5) and exhibit a considerable decline over the latter half of the time-series examined. The 2021 juvenile abundance estimate is 259 million individuals. The 2014 recruitment estimate (230 million individuals) is the lowest on record. The average recruitment (geometric mean) over the time-series is 402 million individuals. Additionally, in the last twenty years only three juvenile abundance estimates (2004-2006) are above the time-series average and in the most recent decade no estimates are above the time-series average (Figure 7). It's important to point out here the consequence of this decline on management reference point estimation. Because equilibrium conditions (i.e., average recruitment) are assumed in reference point estimation, biomass-based management benchmarks will generally be biased when below average conditions persist for extended time periods.

Annual instantaneous fishing mortality estimates range from 0.07-0.82, with peaks in exploitation occurring in 2002, 2012 and 2014 (Table 9, Figure 8). Trends in fishing mortality estimates, 1999-2020, are generally consistent with fishing effort derived from the LDWF Trip Ticket Program (Figure 8). A large reduction in fishing mortality/effort was observed in the years following the passages of Hurricane Katrina and Rita. Fishing effort is not used in the assessment model but is presented here to validate trends in fishing mortality. However, the number of trap fisher trips may not be a suitable measure of fishing effort (specifically for catch per unit effort analysis) if the number of traps fished per trip increases (or decreases) through time and should be considered with caution. Fleet-specific estimates of fishing mortality are presented in the Figure 9.

A downward trend has become apparent between exploitable biomass and subsequent recruitment (Figure 10). With few exceptions, the two most recent decades of data pairs are all below the recruitment time-series average and are some of the lowest adult biomasses observed. However, the 2021 exploitable biomass estimate is the highest observed since 2006.

4.6 Management Benchmarks

Overfishing and overfished limits should be defined for exploitable stocks. The implication is that when biomass falls below a specified limit, there is an unacceptable risk that recruitment will be reduced to undesirable levels. Management actions are needed to avoid approaching this limit and to recover the stock if biomass falls below the limit.

Precautionary limits to fishing were established in an earlier assessment (West et al. 2011) by requiring that exploitable biomass not fall below the three lowest levels observed (1968-2009) where the stock demonstrated sustainability (i.e., no observed declines in recruitment over a wide-range of exploitable biomasses). This is equivalent to maintaining the stock above a limit spawning potential ratio (SPR; Goodyear, 1993). The method for calculating SPR_{limit} or equivalently SSB_{limit} is presented below.

Equilibrium recruitment (under current biomass) is assumed as the average recruitment $\bar{R}$, 1968-2021. This is the horizontal line in Figure 11. Exploitable biomass (i.e., crabs ≥125mm) is used as a measure of spawning stock biomass (SSB). When the stock is in equilibrium, equations [5, 12, and 13] can be rearranged excluding the year and fleet index into SSB/R for any given exploitation rate as:

$$\frac{SSB}{R}|F = \sum_a p_{Na} W_a \times \frac{e^{-M} - F/Z(1-e^{-Z})e^{-0.5M}}{1-[e^{-M} - F/Z(1-e^{-Z})e^{-0.5M}]} \quad [17]$$

where a are ages in months ($a = 1\ to\ 36$), p_{Na} is the proportional equilibrium abundance of crabs ≥125mm (see below), W_a is the average weight-at-age, and M, F, Z are the instantaneous natural, fishing and total mortality rates. Equilibrium abundance-at-age is estimated as:

$$N_a = \bar{R} S_a \quad [18]$$

where survivorship is calculated recursively from $S_a = S_{a-1} e^{-Z_a}$, $S_1 = 1$. Size-at-age, vulnerability-at-age v_a (i.e., knife-edged selection for ages ≥125mm) and resulting monthly mortality vectors (i.e., $Z_a = M/12 + F_a$ and $F_a = v_a F/12$) are derived from the non-seasonal Gompertz growth parameters (Table 4). To approximate changes in growth through the age interval, size-at-age is calculated using the midpoints of the months. Equilibrium N_a of exploitable sized crabs is normalized to 1 as $p_{Na} = \frac{N_{a \geq 125mm}}{\sum_a N_{a \geq 125mm}}$.

If the biomass limit is chosen as the geometric mean of the three lowest exploitable biomasses observed (1968-2009), then the recruitment per SSB (R/SSB_{limit}) that is equivalent to the biomass limit is the slope of the diagonal line from the origin that intersects equilibrium recruitment at SSB_{limit}. This is the left-most diagonal line in Figure 11; unfished recruits per SSB ($R/SSB_{F=0}$) is a slope equivalent to the rightmost diagonal line.

The equilibrium SPR corresponding with the exploitable biomass limit is:

$$SPR_{limit} = \frac{R/SSB_{F=0}}{R/SSB_{limit}} \quad [19]$$

and is estimated to be 23.6%. This is equivalent to specifying SSB_{limit} equal to the average of the three years with the lowest biomasses (1968-2009) in which the stock demonstrated sustainability. Additionally, equations [17, 19] are solved for the fishing mortality rates that correspond with the SPR_{limit} and a SPR_{target} discussed below.

Overfishing, Overfished, and Target Definitions

The existing Louisiana blue crab data does not allow reliable estimates of MSY. Therefore, we have defined a limit based upon the history of the fishery as defined above (i.e., a 23.6% SPR_{limit}). The fishing mortality rate limit F_{limit} and SSB_{limit} that are equivalent to this SPR_{limit} are estimated as 0.86 years^{-1} and 24.5 million pounds, respectively (Table 10).

The targets of fishing, (i.e., SSB, F, and SPR) should not be so close to the limits that the limits are exceeded by random variability of the environment. Therefore, the biomass target reference point SSB_{target} is defined as $SSB_{limit} \times 1.5$, or 36.7 million pounds. This biomass is achieved when there is an equilibrium SPR_{target} of 35.4% and F_{target} of 0.63 years^{-1} (Table 10).

5. Stock Status

The history of the Louisiana blue crab stock relative to the reference points described above is illustrated in Figures 12 and 13. Fishing mortality rates exceeding F_{limit} (or ratios of F/F_{limit}>1.0) indicate overfishing; stock biomasses below SSB_{limit} (or ratios of SSB/SSB_{limit}<1.0) indicate an overfished condition.

Overfishing Status

The 2020 estimate of F/Flimit is 0.41 suggesting the stock is not currently experiencing overfishing. The 2020 fishing mortality rate estimate is also below the fishing mortality target. Estimates of fishing mortality are not available for the terminal year of the assessment.

Overfished Status

The 2021 estimate of SSB/SSBlimit is 2.56, suggesting the stock is currently not in an overfished condition. The 2021 SSB estimate is also above the SSB target. The stock was considered overfished in 1995, 2013, and 2015.

Control Rule

The Louisiana Wildlife and Fisheries Commission adopted a resolution on February 6, 2014 establishing the following policy based on the overfishing and overfished limits and targets of fishing described above: “Should the fishing mortality or exploitable biomass exceed the overfished or overfishing limits, or exceed the targets for three consecutive years, as defined in the most current Louisiana blue crab stock assessment, LDWF shall come before the Commission with an updated assessment and a series of management options for the Commission to review and act upon, intended to keep the fishery from becoming overfished, and that management options for review and action shall include provisions for emergency closures, time based closures, and spatial closures.”

In an earlier assessment update (West et al., 2016), the Louisiana blue crab stock was identified as overfished. Based on that status, the Louisiana Legislature and the Wildlife and Fisheries Commission took actions to reduce harvest. This update assessment is intended to be the second measure of the effectiveness of those management actions enacted.

6. Research and Data Needs

Research emphasis on the Louisiana blue crab fishery is lacking, particularly in consideration of the value and size of the fishery (Guillory et al. 1996). The authors suggest that blue crab research done on the Atlantic coast may not be applicable to Gulf of Mexico populations. Based on this assessment, the following research and data needs are identified as priorities for future assessment of the Louisiana blue crab stock.

Due to the rapid growth and short life span of blue crab an annual time-step in the assessment model may not adequately describe the population dynamics of blue crab. Future assessment modeling efforts should explore finer temporal scales.

Environmental factors influencing year-class strength and the survival of recruits to exploitable life stages are not well understood. Further analysis of these factors could elucidate the link between the environment and blue crab productivity. Contributing factors could also be used in development of predictive models allowing for short-term forecasts for resource managers and industry.

In addition to research specific to the Louisiana blue crab stock, continuous fishery dependent monitoring programs, as part of a comprehensive monitoring plan, are needed. Differences in exploitation rates of male and female blue crabs likely exist. Continuous information on size, sex, and maturity distributions of the commercial and recreational harvest are not available. Continuous harvest data for the recreational sector is also lacking. These data would reduce the number of assumptions required in future assessments.

Commercial effort data is currently only available in terms of the number of trips taken. A more useful measure of effort that could improve future blue crab stock assessment and management is the number of traps fished by basin/season/region.

Estimates of natural mortality in this assessment are based on assumptions of longevity. Without the ability to directly age blue crabs with conventional methods, growth estimation and resulting longevity estimates remain difficult to quantify. Estimates of these life history parameters for the Louisiana blue crab stock, perhaps from tagging or pond studies, would aid in refining life history assumptions in future assessments.

Assessment of regional or basin-specific sub-populations could differentiate exploitation rates and stock status within the state. If available data is adequate for regional assessment, results could be used to determine if regional management is an effective alternative to optimize yield within the state.

The relationship between wetlands losses and the continuation of fishery production within Louisiana has been discussed by numerous authors. Understanding this relationship as it applies to the Louisiana blue crab stock should be an ongoing priority.

With the recent trend toward ecosystem-based assessment models, more data is needed linking blue crab population dynamics to environmental conditions. The addition of environmental data coupled with food web data may lead to a better understanding of the blue crab stock and its habitat.

Fishery dependent data alone is not sufficient to accurately assess stock status and trends in abundance. Consistent fishery independent monitoring, in addition to fishery dependent monitoring, are integral components of this ability. Present monitoring programs should be assessed for adequacy with respect to their ability to evaluate stock status and should be modified or enhanced to optimize their capabilities.

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8. Tables

Table 1: Louisiana blue crab *Callinectes sapidus* landings and dockside value (1968-2021). Landings and values, 1968-1998, are taken from NMFS statistical records. Landings and values, 1999-2021, are taken from the LDWF Trip Ticket Program. Landings are millions of pounds. Values are millions of dollars.

	Total		Hard crab		% Hard crabs		Soft/peeler		% Soft/peeler	
Year	Landings	Value	Landings	Value	Landings	Value	Landings	Value	Landings	Value
1968	9.83	1.01	9.55	0.81	97.11	79.64	0.28	0.21	2.89	20.36
1969	11.80	1.23	11.60	1.07	98.33	86.93	0.20	0.16	1.67	13.07
1970	10.34	1.01	10.25	0.93	99.13	92.11	0.09	0.08	0.87	7.89
1971	12.31	1.38	12.19	1.26	98.97	90.90	0.13	0.13	1.03	9.10
1972	15.18	1.89	15.08	1.78	99.33	94.21	0.10	0.11	0.67	5.79
1973	23.20	2.94	23.08	2.81	99.48	95.53	0.12	0.13	0.52	4.47
1974	20.74	2.83	20.64	2.70	99.54	95.51	0.10	0.13	0.46	4.49
1975	17.25	2.67	17.14	2.51	99.36	94.18	0.11	0.16	0.64	5.82
1976	15.30	3.21	15.21	3.06	99.42	95.48	0.09	0.14	0.58	4.52
1977	16.38	4.33	16.15	3.77	98.63	86.86	0.22	0.57	1.37	13.14
1978	15.21	3.47	15.07	3.19	99.13	92.04	0.13	0.28	0.87	7.96
1979	21.48	5.11	21.33	4.78	99.32	93.40	0.15	0.34	0.68	6.60
1980	18.30	4.60	18.18	4.33	99.35	94.06	0.12	0.27	0.65	5.94
1981	16.34	4.71	16.24	4.47	99.39	94.94	0.10	0.24	0.61	5.06
1982	17.45	5.28	17.28	4.84	99.06	91.82	0.16	0.43	0.94	8.18
1983	19.72	6.66	19.62	6.37	99.49	95.64	0.10	0.29	0.51	4.36
1984	29.69	8.40	29.62	8.19	99.75	97.58	0.08	0.20	0.25	2.42
1985	29.93	8.59	29.85	8.39	99.73	97.68	0.08	0.20	0.27	2.32
1986	31.69	9.48	31.61	9.30	99.75	98.09	0.08	0.18	0.25	1.91
1987	52.48	20.51	52.34	20.13	99.74	98.19	0.14	0.37	0.26	1.81
1988	53.72	21.89	53.55	21.45	99.70	97.99	0.16	0.44	0.30	2.01
1989	33.56	15.20	33.39	14.78	99.49	97.23	0.17	0.42	0.51	2.77
1990	39.14	14.83	38.89	14.21	99.36	95.81	0.25	0.62	0.64	4.19
1991	51.29	17.77	51.09	17.47	99.61	98.32	0.20	0.30	0.39	1.68
1992	51.98	27.20	51.74	26.67	99.54	98.04	0.24	0.53	0.46	1.96
1993	45.95	24.47	45.85	24.04	99.79	98.26	0.10	0.43	0.21	1.74
1994	36.76	22.53	36.66	22.09	99.73	98.07	0.10	0.44	0.27	1.93
1995	36.97	29.54	36.91	29.05	99.86	98.36	0.05	0.48	0.14	1.64
1996	40.00	24.48	39.90	23.96	99.75	97.89	0.10	0.52	0.25	2.11
1997	43.53	27.74	43.44	27.14	99.80	97.86	0.09	0.59	0.20	2.14
1998	43.66	30.74	43.48	29.34	99.59	95.45	0.18	1.40	0.41	4.55
1999	46.66	26.18	46.35	25.46	99.33	97.25	0.31	0.72	0.67	2.75
2000	52.05	34.41	51.45	33.25	98.84	96.62	0.60	1.16	1.16	3.38
2001	41.87	32.05	41.46	30.98	99.04	96.66	0.40	1.07	0.96	3.34
2002	50.08	30.69	49.71	29.76	99.26	96.99	0.37	0.92	0.74	3.01
2003	48.09	33.63	47.70	32.60	99.20	96.94	0.38	1.03	0.80	3.06
2004	44.41	29.70	44.08	28.83	99.26	97.08	0.33	0.87	0.74	2.92
2005	38.12	27.41	37.90	26.83	99.42	97.89	0.22	0.58	0.58	2.11
2006	53.29	32.31	53.15	31.91	99.74	98.77	0.14	0.40	0.26	1.23
2007	46.20	35.77	46.00	35.22	99.56	98.45	0.20	0.55	0.44	1.55
2008	44.66	34.61	44.56	34.32	99.77	99.15	0.10	0.29	0.23	0.85
2009	54.99	38.43	54.78	37.89	99.62	98.59	0.21	0.54	0.38	1.41
2010	30.90	30.50	30.76	30.11	99.56	98.69	0.13	0.40	0.44	1.31
2011	43.97	36.90	43.78	36.32	99.57	98.41	0.19	0.58	0.43	1.59
2012	46.38	44.15	46.22	43.64	99.65	98.84	0.16	0.51	0.35	1.16
2013	39.22	51.65	39.08	51.24	99.64	99.20	0.14	0.41	0.36	0.80
2014	43.30	67.16	43.13	66.66	99.61	99.25	0.17	0.50	0.39	0.75
2015	41.47	58.43	41.28	57.88	99.55	99.07	0.19	0.55	0.45	0.93
2016	40.79	50.18	40.63	49.71	99.61	99.06	0.16	0.47	0.39	0.94
2017	44.37	55.13	44.25	54.74	99.72	99.29	0.12	0.39	0.28	0.71
2018	45.16	63.70	45.05	63.32	99.76	99.40	0.11	0.38	0.24	0.60
2019	40.33	55.73	40.24	55.42	99.76	99.44	0.10	0.31	0.24	0.56
2020	39.80	63.48	39.73	63.28	99.81	99.69	0.07	0.20	0.19	0.31
2021	47.36	90.13	47.29	89.94	99.86	99.79	0.07	0.18	0.14	0.21

Table 2: Louisiana blue crab *Callinectes sapidus* bycatch estimate time-series of the inshore shrimp fishery (1968-2021) and parameter values used to expand the estimates from the annual inshore shrimp landings. Inshore shrimp landings and the bycatch to shrimp ratio include brown, white, and seabob shrimp. Landings and bycatch values are reported in millions.

Parameter (source)	Value
Bycatch/ shrimp ratio in units of weight (Cagle and West 2020)	1.01
Blue crab species composition in units of weight (Cagle and West 2020)	0.0499
Blue crab mean weight (lbs; Cagle and West 2020)	0.118
Blue crab trawl caught discard mortality rate (Logothetis and McCuiston 2006)	0.360

Year	Inshore Shrimp Landings (lbs)	Crab bycatch (lbs)	Crab bycatch (numbers) Total	Dead	Live
1968	34.80	1.76	14.89	5.36	9.53
1969	42.43	2.15	18.15	6.53	11.62
1970	46.64	2.36	19.95	7.18	12.77
1971	47.45	2.40	20.30	7.31	12.99
1972	50.25	2.54	21.50	7.74	13.76
1973	50.25	2.54	21.50	7.74	13.76
1974	50.25	2.54	21.50	7.74	13.76
1975	50.25	2.54	21.50	7.74	13.76
1976	50.25	2.54	21.50	7.74	13.76
1977	60.31	3.00	25.39	9.14	16.25
1978	47.45	2.36	19.97	7.19	12.78
1979	38.73	1.93	16.30	5.87	10.43
1980	39.33	1.96	16.55	5.96	10.59
1981	60.07	2.99	25.29	9.10	16.18
1982	51.98	2.59	21.88	7.88	14.00
1983	43.71	2.17	18.40	6.62	11.78
1984	58.69	2.92	24.71	8.89	15.81
1985	56.86	2.83	23.93	8.62	15.32
1986	79.69	3.96	33.54	12.08	21.47
1987	63.84	3.18	26.87	9.67	17.20
1988	60.37	3.00	25.41	9.15	16.26
1989	52.55	2.61	22.12	7.96	14.16
1990	72.02	3.58	30.32	10.91	19.40
1991	46.00	2.29	19.36	6.97	12.39
1992	48.41	2.41	20.38	7.34	13.04
1993	46.18	2.30	19.44	7.00	12.44
1994	47.78	2.38	20.11	7.24	12.87
1995	59.63	2.97	25.10	9.04	16.06
1996	47.97	2.39	20.19	7.27	12.92
1997	49.94	2.48	21.02	7.57	13.45
1998	68.09	3.39	28.66	10.32	18.34
1999	77.41	3.85	32.58	11.73	20.85
2000	95.12	4.73	40.04	14.41	25.63
2001	85.37	4.25	35.93	12.94	23.00
2002	61.59	3.06	25.92	9.33	16.59
2003	77.79	3.87	32.75	11.79	20.96
2004	84.94	4.23	35.75	12.87	22.88
2005	65.18	3.24	27.44	9.88	17.56
2006	90.03	4.48	37.90	13.64	24.25
2007	79.10	3.94	33.30	11.99	21.31
2008	66.88	3.33	28.15	10.14	18.02
2009	74.66	3.71	31.43	11.31	20.11
2010	58.94	2.93	24.81	8.93	15.88
2011	69.39	3.45	29.21	10.52	18.69
2012	71.96	3.58	30.29	10.90	19.38
2013	72.76	3.62	30.63	11.03	19.60
2014	90.91	4.52	38.27	13.78	24.49
2015	74.47	3.71	31.35	11.29	20.06
2016	76.62	3.81	32.25	11.61	20.64
2017	67.40	3.35	28.37	10.21	18.16
2018	73.95	3.68	31.13	11.21	19.92
2019	66.06	3.29	27.80	10.01	17.79
2020	54.08	2.69	22.76	8.19	14.57
2021	54.58	2.72	22.98	8.27	14.70

Table 3: Catch-per-unit-effort of adult, juvenile, and young-of-the-year blue crab *Callinectes sapidus*. Abundance indices are the delta-lognormal means of the adult, juvenile, and young-of-the-year crabs per tow from the LDWF fishery-independent marine trawl survey.

Catch-per-unit-effort (crabs per tow)						
	Adults		Juveniles		Young-of-year	
Year	Index	CV	Index	CV	Index	CV
1967	0.88	0.53	0.97	0.42	0.38	0.56
1968	0.74	0.53	1.28	0.36	0.40	0.47
1969	0.66	0.59	1.64	0.36	0.22	0.54
1970	1.12	0.50	1.24	0.43	0.49	0.44
1971	1.08	0.46	1.52	0.32	0.64	0.36
1972	0.88	0.51	1.63	0.29	0.43	0.42
1973	0.93	0.47	1.65	0.29	0.45	0.41
1974	1.04	0.46	1.71	0.30	0.19	0.57
1975	0.78	0.50	1.28	0.36	0.23	0.53
1976	0.45	0.62	0.67	0.45	0.31	0.44
1977	0.37	0.73	0.78	0.48	0.30	0.49
1978	0.53	0.63	0.98	0.40	0.39	0.55
1979	0.75	0.55	2.14	0.28	0.79	0.36
1980	1.01	0.47	2.35	0.24	0.51	0.41
1981	0.88	0.50	1.74	0.31	0.39	0.40
1982	0.63	0.50	2.17	0.25	0.86	0.30
1983	0.63	0.54	2.27	0.27	0.55	0.38
1984	0.86	0.48	1.83	0.31	0.52	0.42
1985	0.79	0.53	1.80	0.30	0.55	0.37
1986	0.75	0.56	1.65	0.33	0.46	0.36
1987	0.57	0.59	1.97	0.29	0.56	0.35
1988	0.50	0.60	2.23	0.24	0.38	0.49
1989	0.41	0.61	1.75	0.29	0.48	0.36
1990	0.84	0.46	2.53	0.24	0.78	0.28
1991	0.70	0.50	2.86	0.21	0.41	0.42
1992	0.32	0.69	1.38	0.33	0.40	0.37
1993	0.38	0.62	1.84	0.27	0.80	0.30
1994	0.27	0.71	2.07	0.23	0.53	0.35
1995	0.14	0.88	1.18	0.36	0.44	0.40
1996	0.19	0.75	1.16	0.36	0.42	0.41
1997	0.27	0.74	1.13	0.36	0.87	0.27
1998	0.30	0.68	1.38	0.33	0.34	0.49
1999	0.32	0.63	0.93	0.39	0.46	0.33
2000	0.30	0.66	1.03	0.36	0.32	0.42
2001	0.21	0.77	0.72	0.41	0.33	0.46
2002	0.33	0.62	0.81	0.44	0.27	0.55
2003	0.19	0.71	0.64	0.44	0.33	0.43
2004	0.24	0.67	0.90	0.41	0.50	0.38
2005	0.54	0.50	1.10	0.37	0.32	0.49
2006	1.06	0.45	1.29	0.35	0.19	0.64
2007	0.51	0.56	1.00	0.41	0.24	0.56
2008	0.40	0.60	0.79	0.45	0.25	0.56
2009	0.53	0.55	0.93	0.42	0.21	0.62
2010	0.31	0.62	0.60	0.48	0.16	0.62
2011	0.50	0.49	0.94	0.37	0.25	0.44
2012	0.25	0.64	0.66	0.45	0.14	0.57
2013	0.17	0.72	0.71	0.47	0.18	0.53
2014	0.29	0.58	0.68	0.46	0.25	0.46
2015	0.16	0.77	0.74	0.40	0.20	0.62
2016	0.33	0.68	0.61	0.52	0.28	0.54
2017	0.29	0.69	0.45	0.61	0.16	0.73
2018	0.51	0.53	0.61	0.51	0.17	0.62
2019	0.30	0.62	0.49	0.58	0.24	0.60
2020	0.52	0.52	0.76	0.48	0.24	0.53
2021	0.65	0.46	0.72	0.49	0.18	0.66

Table 4: Gompertz growth parameters of blue crab *Callinectes sapidus* from West et al. (2011). Sizes are carapace-widths in mm.

	Gompertz parameters			
	Jan-Apr	May-Aug	Sept-Dec	non-seasonal
CW_{∞}	164.8	175.9	174.8	174.5
α	-4.9	-4.6	-19.8	-5.5
β	-3.5	-2.6	-4.4	-3

Table 5: Size-at-capture table of Louisiana blue crab *Callinectes sapidus* used to identify crabs that will not recruit to the fishery during the survey year. Cells represent carapace-widths at capture in mm from the LDWF fishery independent trawl survey. Crabs not fully-selected by the survey gear (<25mm) are not shown (i.e., blank cells). Month of capture represents samples from the trawl survey. Month of hatch represents monthly crab cohorts. Cells above the diagonal represent size-at-capture of the current year-class. Cells below the diagonal are size-at-capture of the previous year-class. The shaded area represents cohorts that will not recruit to the fishery during the survey year. Carapace widths in bold represent the maximum size-at-capture of crabs that will not recruit to the fishery during the survey year. Seasonal size-at-age (Jan-Apr, May-Aug, and Sept-Dec) is estimated from Gompertz growth models.

	Month of Capture											
Month of Hatch	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Jan				29	45	63	80	96	110	122	132	140
Feb	140				29	45	63	80	96	110	122	132
Mar	132	140				**29**	**45**	**63**	**80**	**96**	**110**	**122**
Apr	122	132	140				29	45	63	80	96	110
May	85	98	110	120					31	44	57	71
Jun	71	85	98	110	120					31	44	57
Jul	57	71	85	98	110	120					31	44
Aug	44	57	71	85	98	110	120					31
Sept			28	50	73	95	115	131				
Oct				28	50	73	95	115	131			
Nov					28	50	73	95	115	131		
Dec						28	50	73	95	115	131	

Table 6: FAO proposed guideline for indices of productivity for exploited aquatic species. Parameter values are taken from West et al. (2011) and GDAR1.

Parameter	Productivity			Species	
	Low	Medium	High	Blue Crab	Score
M	<0.2	0.2 - 0.5	>0.5	1.0	3
K	<0.15	0.15 - 0.33	>0.33	1.9	3
t_{mat}	>8	3.3 - 8	<3.3	1	3
t_{max}	>25	14 - 25	<14	3	3
Examples	orange roughy, many sharks	cod, hake	sardine, anchovy	Blue Crab Productivity Score = 3.0 (high)	

Table 7: Annual mean weights (pounds) of juvenile and adult blue crabs captured from the LDWF fishery-independent marine trawl survey, 1968-2021. Adult crabs are≥125mm carapace width. Juveniles are crabs ≥25mm and <125mm carapace width.

	Mean Weight (lbs)	
Year	Adults	Juveniles
1968	0.40	0.05
1969	0.42	0.05
1970	0.41	0.06
1971	0.41	0.05
1972	0.41	0.05
1973	0.42	0.06
1974	0.42	0.06
1975	0.40	0.05
1976	0.44	0.05
1977	0.42	0.04
1978	0.42	0.05
1979	0.42	0.05
1980	0.42	0.04
1981	0.39	0.06
1982	0.39	0.05
1983	0.38	0.05
1984	0.40	0.06
1985	0.40	0.06
1986	0.38	0.05
1987	0.37	0.06
1988	0.40	0.05
1989	0.38	0.05
1990	0.38	0.05
1991	0.39	0.05
1992	0.39	0.04
1993	0.39	0.03
1994	0.40	0.03
1995	0.39	0.03
1996	0.40	0.03
1997	0.39	0.03
1998	0.40	0.03
1999	0.39	0.03
2000	0.42	0.03
2001	0.44	0.03
2002	0.42	0.04
2003	0.46	0.03
2004	0.45	0.03
2005	0.45	0.03
2006	0.44	0.04
2007	0.42	0.04
2008	0.44	0.03
2009	0.44	0.05
2010	0.43	0.04
2011	0.46	0.04
2012	0.46	0.03
2013	0.48	0.03
2014	0.47	0.03
2015	0.46	0.02
2016	0.45	0.04
2017	0.46	0.04
2018	0.48	0.04
2019	0.46	0.03
2020	0.48	0.06
2021	0.45	0.07

Table 8: Catch-per-unit-effort of blue crab *Callinectes sapidus*. Adult, juvenile, and young-of-the-year abundance indices are derived as the delta-lognormal mean catch-per-tow from the LDWF fishery-independent marine trawl survey, 1967-2021. The juvenile abundance index r_y used in the catch-survey model is derived as the sum of young-of-the-year cpue in year and juvenile cpue in year+1. The shaded cells represent values not used as model inputs.

	Catch-per-unit-effort (crabs per tow)			Model inputs	
Year	Adults	Juveniles	Young-of-the-year	n_y	r_y
1967	0.88	0.97	0.38		
1968	0.74	1.28	0.40	0.74	1.66
1969	0.66	1.64	0.22	0.66	2.03
1970	1.12	1.24	0.49	1.12	1.46
1971	1.08	1.52	0.64	1.08	2.01
1972	0.88	1.63	0.43	0.88	2.27
1973	0.93	1.65	0.45	0.93	2.08
1974	1.04	1.71	0.19	1.04	2.16
1975	0.78	1.28	0.23	0.78	1.46
1976	0.45	0.67	0.31	0.45	0.90
1977	0.37	0.78	0.30	0.37	1.09
1978	0.53	0.98	0.39	0.53	1.28
1979	0.75	2.14	0.79	0.75	2.52
1980	1.01	2.35	0.51	1.01	3.14
1981	0.88	1.74	0.39	0.88	2.25
1982	0.63	2.17	0.86	0.63	2.55
1983	0.63	2.27	0.55	0.63	3.14
1984	0.86	1.83	0.52	0.86	2.38
1985	0.79	1.80	0.55	0.79	2.32
1986	0.75	1.65	0.46	0.75	2.20
1987	0.57	1.97	0.56	0.57	2.44
1988	0.50	2.23	0.38	0.50	2.79
1989	0.41	1.75	0.48	0.41	2.12
1990	0.84	2.53	0.78	0.84	3.01
1991	0.70	2.86	0.41	0.70	3.64
1992	0.32	1.38	0.40	0.32	1.79
1993	0.38	1.84	0.80	0.38	2.24
1994	0.27	2.07	0.53	0.27	2.87
1995	0.14	1.18	0.44	0.14	1.71
1996	0.19	1.16	0.42	0.19	1.61
1997	0.27	1.13	0.87	0.27	1.54
1998	0.30	1.38	0.34	0.30	2.25
1999	0.32	0.93	0.46	0.32	1.27
2000	0.30	1.03	0.32	0.30	1.49
2001	0.21	0.72	0.33	0.21	1.04
2002	0.33	0.81	0.27	0.33	1.14
2003	0.19	0.64	0.33	0.19	0.91
2004	0.24	0.90	0.50	0.24	1.22
2005	0.54	1.10	0.32	0.54	1.60
2006	1.06	1.29	0.19	1.06	1.61
2007	0.51	1.00	0.24	0.51	1.19
2008	0.40	0.79	0.25	0.40	1.03
2009	0.53	0.93	0.21	0.53	1.18
2010	0.31	0.60	0.16	0.31	0.81
2011	0.50	0.94	0.25	0.50	1.10
2012	0.25	0.66	0.14	0.25	0.90
2013	0.17	0.71	0.18	0.17	0.84
2014	0.29	0.68	0.25	0.29	0.85
2015	0.16	0.74	0.20	0.16	0.99
2016	0.33	0.61	0.28	0.33	0.82
2017	0.29	0.45	0.16	0.29	0.73
2018	0.51	0.61	0.17	0.51	0.76
2019	0.30	0.49	0.24	0.30	0.67
2020	0.52	0.76	0.24	0.52	1.00
2021	0.65	0.72	0.18	0.65	0.96

Table 9: Assessment model inputs and resulting estimates for the Louisiana blue crab *Callinectes sapidus* stock, 1968-2021. Descriptions of model inputs are: M = constant instantaneous natural mortality rate, C_y = harvest (as individuals), r_y = juvenile cpue, n_y = adult cpue, s_r = relative selectivity of juveniles to adult crabs in the survey gear. Descriptions of model estimates are: $\hat{q}_n$ = predicted catchability of adult crabs to the survey gear, $\hat{r}_y$ = predicted juvenile cpue, $\hat{n}_y$ = predicted adult cpue, n_y = calculated adult cpue (i.e., from process error), R_y = juvenile abundance, N_y = adult abundance, Z_y = instantaneous total mortality rate, u_y = exploitation rate, F_y = instantaneous fishing mortality rate. CPUE is derived as the delta-lognormal mean catch per tow from the LDWF fishery-independent trawl survey. Juveniles are crabs ≥25mm and <125mm carapace width. Adult crabs are ≥125mm carapace width. Abundance units are millions of individuals. Biomass units are millions of pounds.

Model inputs $M = 1.0$					Model estimates $q = 0.00372$									
Year	C_y	r_y	n_y	s_r	$\hat{r}_y$	$\hat{n}_y$	n_y	R_y	N_y	Z_y	u_y	F_y	R_y Biomass	N_y Biomass
1968	30.21	1.66	0.74	1.00	1.57	0.72	--	423.09	194.71	1.16	0.05	0.08	22.98	78.58
1969	35.34	2.03	0.66	1.00	2.18	0.72	0.78	586.27	194.12	0.99	0.05	0.07	30.92	82.10
1970	33.50	1.46	1.12	1.00	1.54	1.07	0.99	415.83	288.97	0.99	0.05	0.07	24.70	118.24
1971	38.55	2.01	1.08	1.00	1.93	0.97	0.89	519.10	260.90	1.14	0.05	0.08	23.73	106.85
1972	46.50	2.27	0.88	1.00	2.17	0.92	0.98	585.31	248.24	1.15	0.06	0.09	27.49	101.42
1973	65.97	2.08	0.93	1.00	2.08	0.98	1.03	559.75	263.65	1.14	0.08	0.13	31.82	109.72
1974	58.90	2.16	1.04	1.00	1.94	0.98	0.98	522.94	263.47	1.27	0.07	0.13	32.51	111.60
1975	53.07	1.46	0.78	1.00	1.27	0.82	0.94	342.40	220.33	1.36	0.09	0.17	18.11	87.50
1976	43.91	0.90	0.45	1.00	0.86	0.53	0.65	232.22	143.96	1.26	0.12	0.21	11.54	63.58
1977	49.63	1.09	0.37	1.00	1.18	0.40	0.42	317.15	106.39	1.13	0.12	0.20	13.79	44.57
1978	45.06	1.28	0.53	1.00	1.41	0.51	0.47	378.18	136.71	1.05	0.09	0.14	19.56	57.13
1979	59.62	2.52	0.75	1.00	2.45	0.67	0.60	659.48	180.69	1.16	0.07	0.12	36.20	75.30
1980	51.76	3.14	1.01	1.00	2.66	0.98	1.01	715.26	263.91	1.30	0.05	0.09	29.44	110.02
1981	52.99	2.25	0.88	1.00	1.89	0.99	1.22	508.97	266.64	1.35	0.07	0.12	29.05	103.57
1982	54.00	2.55	0.63	1.00	2.13	0.74	0.94	573.12	200.26	1.34	0.07	0.13	27.58	78.79
1983	60.58	3.14	0.63	1.00	2.72	0.75	0.94	732.71	202.88	1.27	0.06	0.11	37.19	77.45
1984	86.34	2.38	0.86	1.00	2.15	0.97	1.14	579.93	261.62	1.30	0.10	0.18	34.09	105.05
1985	87.41	2.32	0.79	1.00	2.09	0.85	0.96	563.78	228.58	1.32	0.11	0.20	31.43	90.92
1986	98.72	2.20	0.75	1.00	1.88	0.79	0.89	505.33	212.02	1.43	0.14	0.26	26.57	81.22
1987	157.98	2.44	0.57	1.00	2.04	0.64	0.76	549.85	171.40	1.60	0.22	0.44	30.73	63.52
1988	149.84	2.79	0.50	1.00	2.13	0.54	0.63	572.75	146.26	1.64	0.21	0.42	25.85	58.46
1989	101.28	2.12	0.41	1.00	2.16	0.52	0.65	582.23	138.89	1.25	0.14	0.25	27.09	52.18
1990	118.17	3.01	0.84	1.00	2.44	0.77	0.76	656.08	207.51	1.47	0.14	0.26	33.03	79.00
1991	144.92	3.64	0.70	1.00	2.23	0.74	0.91	601.33	198.72	1.81	0.18	0.39	31.00	77.28
1992	145.75	1.79	0.32	1.00	1.57	0.49	0.77	421.43	131.06	1.67	0.26	0.54	16.72	51.44
1993	129.40	2.24	0.38	1.00	1.52	0.39	0.43	410.25	103.85	1.82	0.25	0.55	13.25	40.84
1994	103.20	2.87	0.27	1.00	1.39	0.31	0.41	374.34	83.36	2.02	0.23	0.53	11.20	33.44
1995	108.17	1.71	0.14	1.00	1.21	0.23	0.39	326.52	60.66	1.84	0.28	0.61	11.35	23.72
1996	112.78	1.61	0.19	1.00	1.35	0.23	0.29	362.44	61.63	1.69	0.27	0.55	11.41	24.47
1997	123.05	1.54	0.27	1.00	1.37	0.29	0.33	368.06	78.04	1.69	0.28	0.57	12.32	30.82
1998	124.88	2.25	0.30	1.00	1.72	0.31	0.33	464.25	82.57	1.67	0.23	0.47	16.22	32.90
1999	135.00	1.27	0.32	1.00	1.24	0.38	0.47	334.80	103.14	1.72	0.31	0.65	10.86	40.72
2000	141.72	1.49	0.30	1.00	1.27	0.29	0.29	341.64	78.12	1.90	0.34	0.75	11.03	33.15
2001	113.01	1.04	0.21	1.00	1.20	0.23	0.25	322.34	62.76	1.57	0.29	0.58	9.62	27.30
2002	133.56	1.14	0.33	1.00	1.09	0.30	0.27	294.52	79.84	1.91	0.36	0.80	10.66	33.55
2003	121.74	0.91	0.19	1.00	1.10	0.21	0.21	296.60	55.53	1.75	0.35	0.73	8.81	25.30
2004	116.09	1.22	0.24	1.00	1.57	0.23	0.21	422.81	61.39	1.33	0.24	0.43	11.18	27.53
2005	97.52	1.60	0.54	1.00	1.99	0.48	0.40	536.00	128.10	1.07	0.15	0.24	14.38	58.16
2006	140.51	1.61	1.06	1.00	1.55	0.85	0.69	417.31	227.95	1.48	0.22	0.42	16.70	100.27
2007	127.69	1.19	0.51	1.00	1.28	0.55	0.57	344.51	146.74	1.50	0.26	0.50	13.22	61.25
2008	116.05	1.03	0.40	1.00	1.32	0.41	0.38	354.96	109.78	1.34	0.25	0.45	12.20	48.49
2009	141.71	1.18	0.53	1.00	1.26	0.45	0.37	338.98	121.68	1.66	0.31	0.63	15.49	53.67
2010	84.15	0.81	0.31	1.00	1.05	0.32	0.31	283.43	87.30	1.25	0.23	0.40	11.53	37.49
2011	111.16	1.10	0.50	1.00	1.04	0.39	0.32	280.20	105.86	1.68	0.29	0.60	12.48	48.35
2012	115.40	0.90	0.25	1.00	0.92	0.27	0.28	247.80	71.75	1.89	0.36	0.81	7.12	33.32
2013	96.30	0.84	0.17	1.00	1.04	0.18	0.18	278.70	48.06	1.54	0.29	0.58	9.24	23.13
2014	109.50	0.85	0.29	1.00	0.86	0.26	0.23	230.40	69.95	1.92	0.36	0.82	7.70	33.09
2015	106.07	0.99	0.16	1.00	1.22	0.16	0.16	329.59	44.22	1.50	0.28	0.55	8.18	20.22
2016	105.71	0.82	0.33	1.00	1.01	0.31	0.27	272.69	83.11	1.53	0.30	0.58	9.62	37.69
2017	110.89	0.73	0.29	1.00	1.19	0.29	0.25	319.15	77.18	1.29	0.28	0.50	12.50	35.62
2018	109.19	0.76	0.51	1.00	0.95	0.41	0.29	256.25	109.14	1.52	0.30	0.58	9.76	52.68
2019	101.06	0.67	0.30	1.00	1.09	0.30	0.25	293.01	79.91	1.25	0.27	0.47	9.86	37.08
2020	95.53	1.00	0.52	1.00	1.31	0.40	0.28	352.26	107.01	1.19	0.21	0.36	20.26	51.11
2021	118.75	0.96	0.65	1.00	--	0.52	0.41	258.56	139.54	--	0.30	--	18.20	62.72

Table 10: Derivation and management reference point estimates for the Louisiana blue crab *Callinectes sapidus* stock. Fishing mortality units are per year. Biomass units are millions of pounds.

Management Benchmarks		
Parameter	Derivation	Estimate
SPR_{limit}	Equations [17,19] and SSB_{limit}	23.6%
SSB_{limit}	Geometric mean of 3 lowest SSB's (1968-2009)	24.5
F_{limit}	Equations [17,19] and SPR_{limit}	0.864
SPR_{target}	Equations [17,19] and SSB_{target}	35.4%
SSB_{target}	SSB_{limit} *1.5	36.7
F_{target}	Equations [17,19] and SPR_{target}	0.627

9. Figures

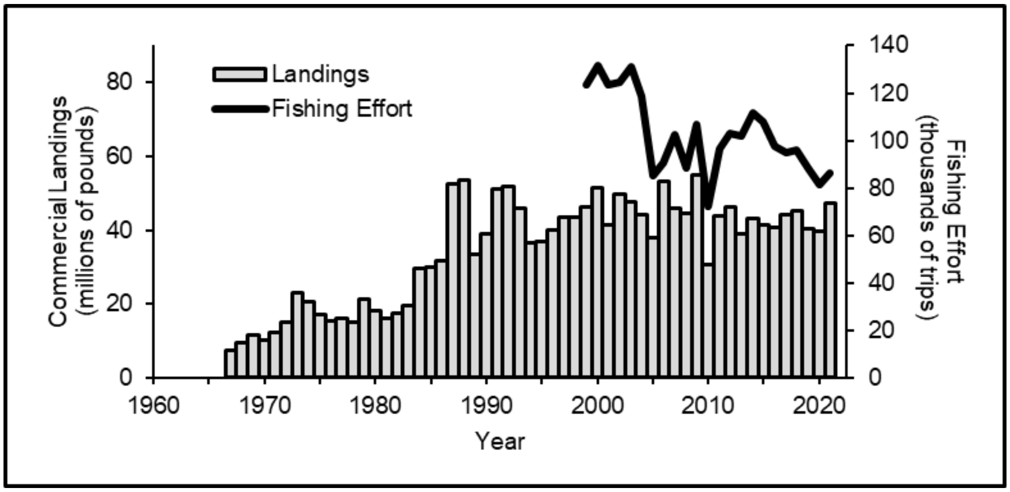


Figure 1: Commercial hard crab landings and fishing effort for Louisiana blue crab *Callinectes sapidus*. Landings, 1967-1998, are taken from NMFS statistical records. Landings and fishing effort, 1999-2021, are taken from the LDWF Trip Ticket Program. Landings are millions of pounds. Fishing effort is thousands of commercial hard crab trips.

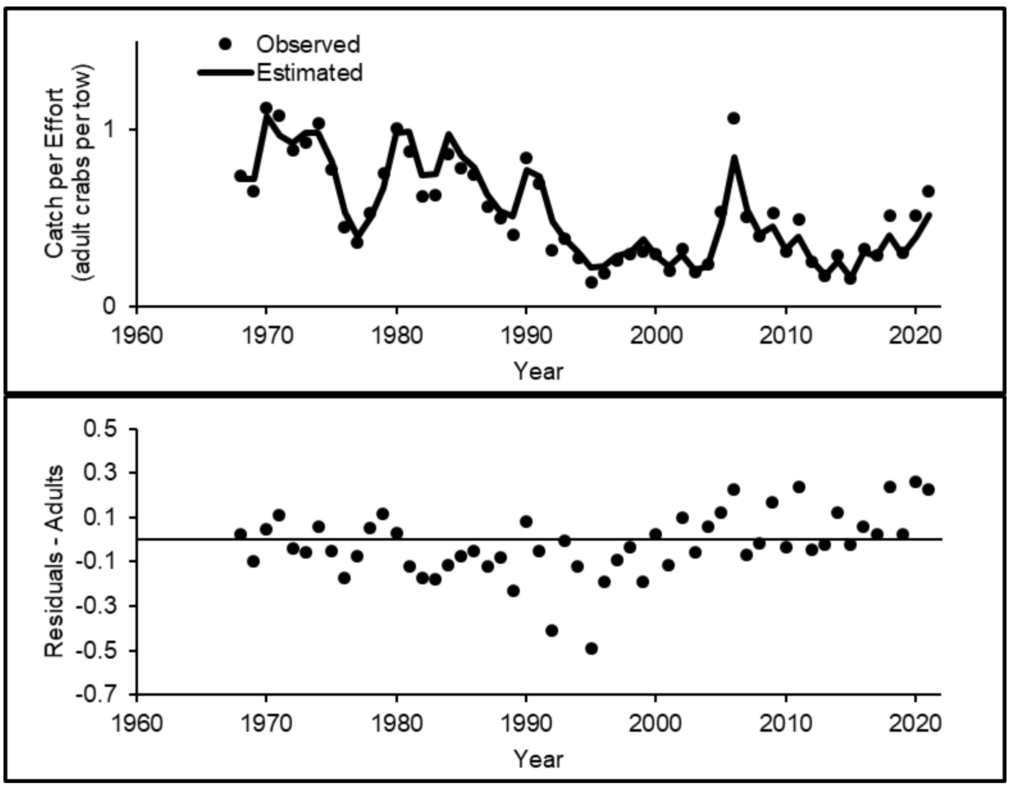


Figure 2: Catch-per-unit-effort of adult Louisiana blue crab *Callinectes sapidus*. The predicted index is derived from lognormal observation error of the catch-survey model. The observed index is the delta-lognormal mean catch-per-tow from the LDWF fishery-independent trawl survey, 1968-2021. Bottom graphic depicts lognormal residuals. Adult crabs are ≥125mm carapace-width.

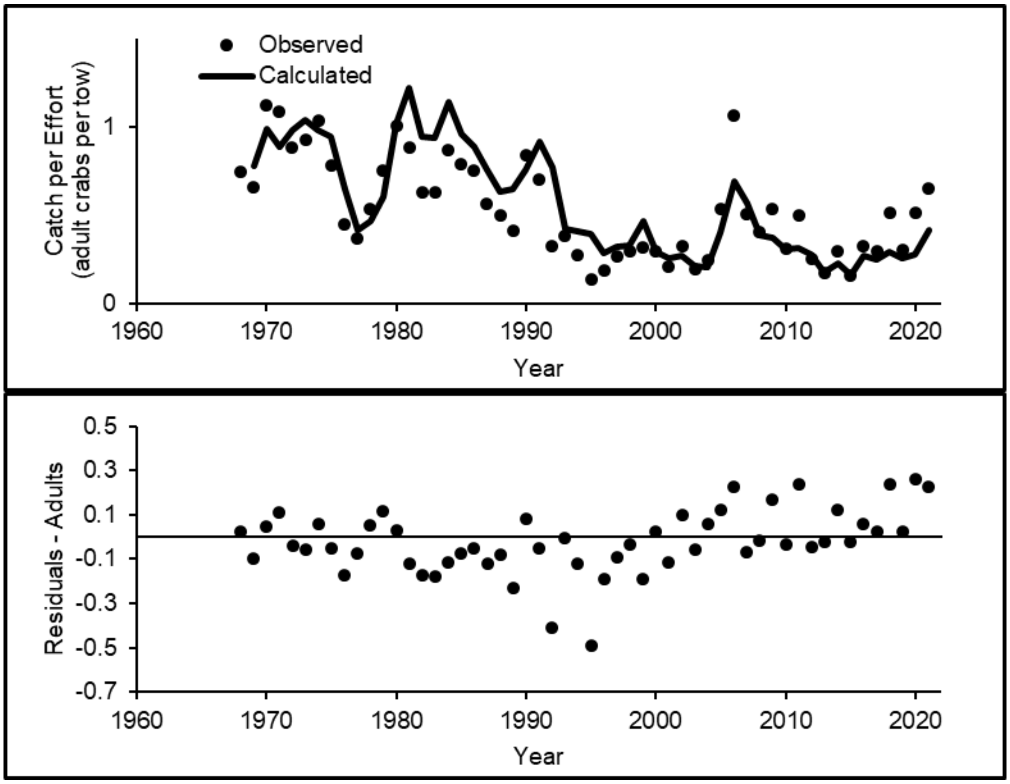


Figure 3: Catch-per-unit-effort of adult Louisiana blue crab *Callinectes sapidus.* The calculated index is derived from lognormal process error of the catch-survey model. The observed index is the delta-lognormal mean catch-per-tow from the LDWF fishery-independent trawl survey, 1968-2021. Bottom graphic depicts lognormal residuals. Adult crabs are ≥125mm carapace-width.

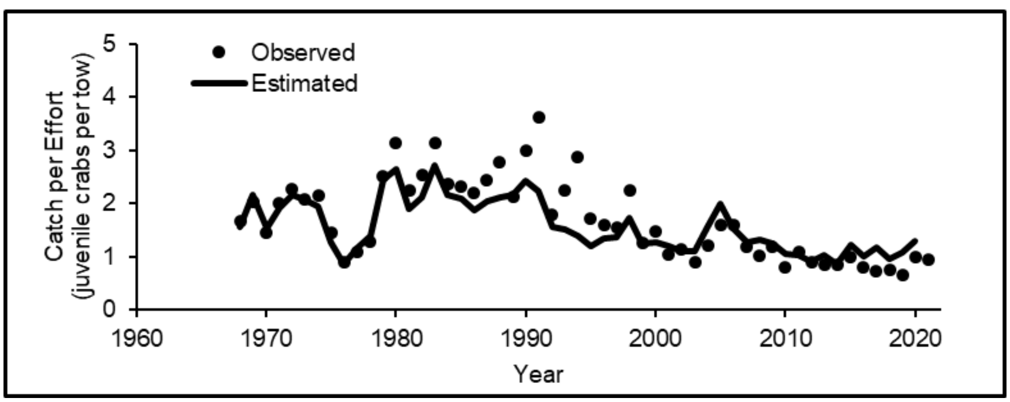


Figure 4: Catch-per-unit-effort of juvenile Louisiana blue crab *Callinectes sapidus*. The predicted index is derived from lognormal observation error of the catch-survey model. The observed index is the delta-lognormal mean catch-per-tow from the LDWF fishery-independent trawl survey, 1968-2021. Bottom graphic depicts lognormal residuals. Juveniles are crabs ≥25mm and <125mm carapace-width.

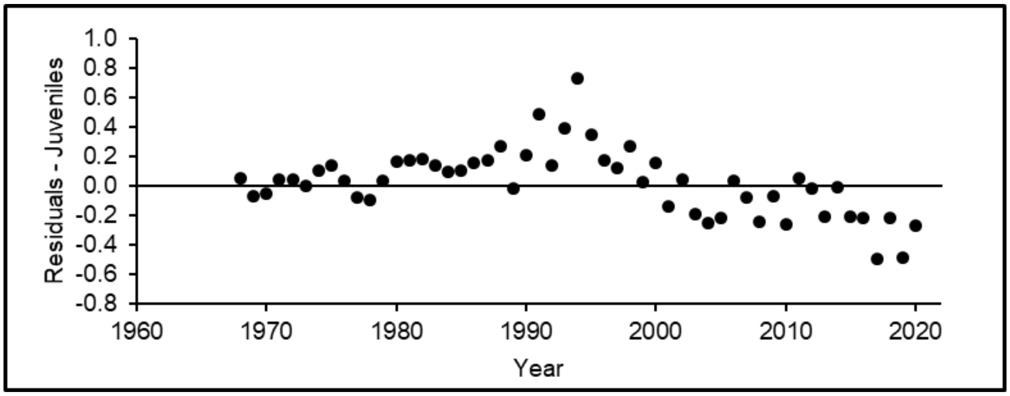
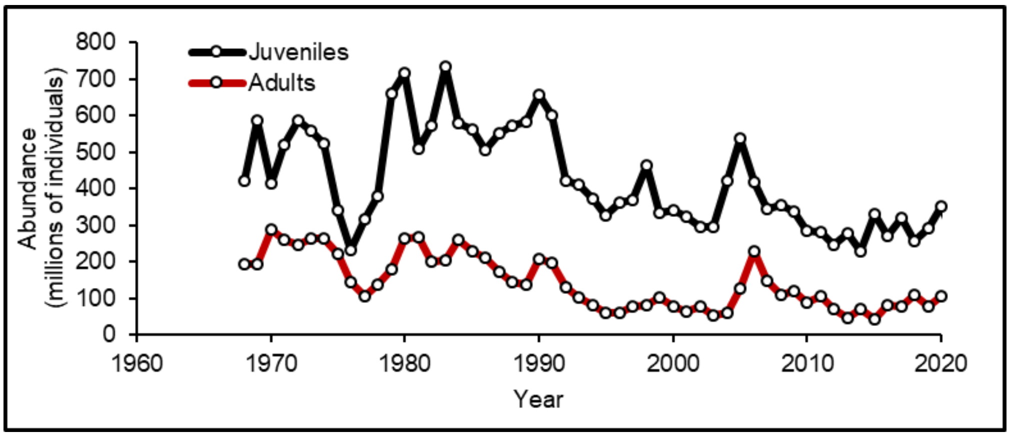


Figure 4 (continued):



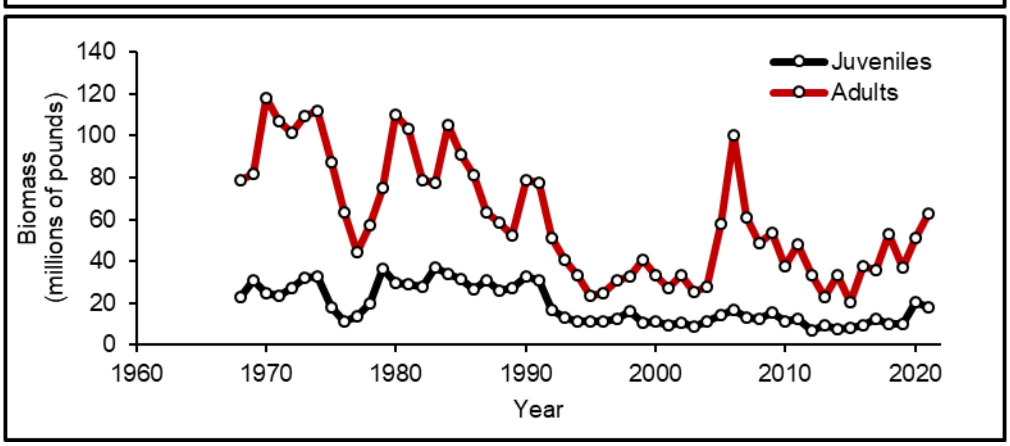


Figure 5: Abundance (top graphic) and biomass estimates (bottom graphic) of Louisiana blue crab *Callinectes sapidus* derived from the catch-survey model. Abundance units are millions of individuals. Biomass units are millions of pounds. Juveniles are crabs ≥25mm and <125mm carapace width. Adult crabs are ≥125mm carapace width.

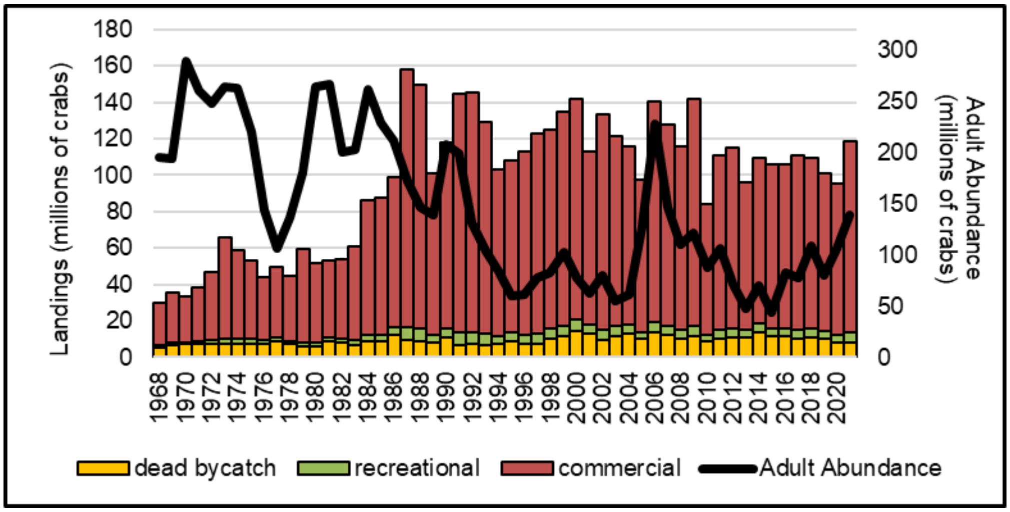


Figure 6: Estimated adult abundance and observed and estimated harvest of Louisiana blue crab *Callinectes sapidus*. Abundance is estimated from the catch-survey model. Commercial hard crab landings are expanded by 5% to approximate for recreational harvest. Units are millions of individuals.

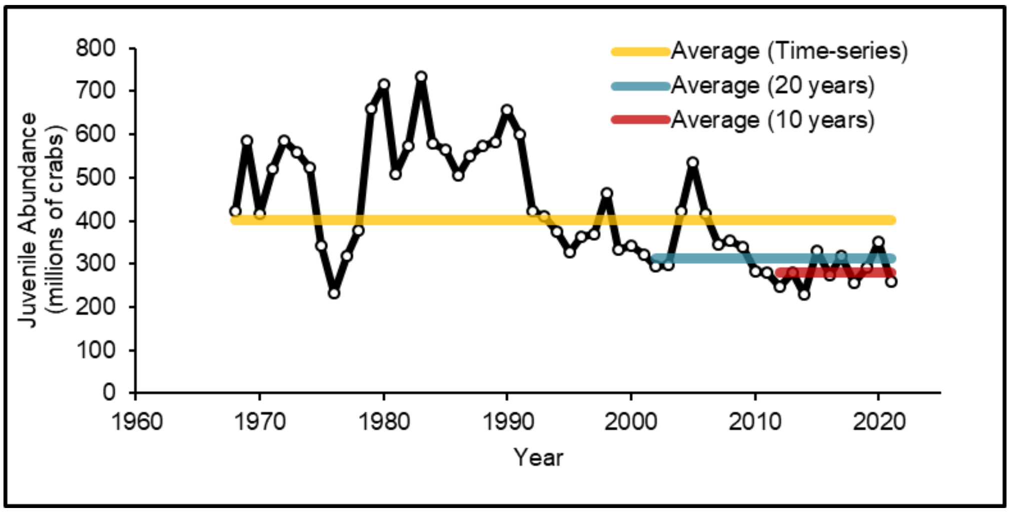


Figure 7: Juvenile abundance estimates of Louisiana blue crab *Callinectes sapidus* derived from the catch-survey model. Units are millions of individuals. Juveniles are crabs ≥25mm and <125mm carapace width. The yellow horizontal is the average (geometric mean) juvenile abundance across the time-series. The blue and red horizontals are the most recent 20 and 10 year averages.

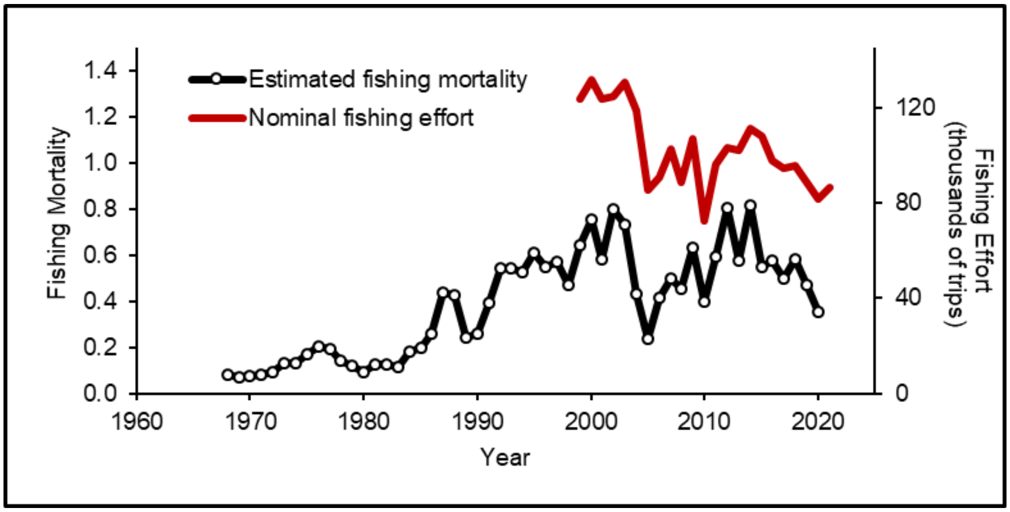


Figure 8: Estimated fishing mortality and nominal fishing effort for Louisiana blue crab *Callinectes sapidus*. Fishing mortality, 1968-2020, is estimated from the catch-survey model. Fishing effort, 1999-2021, is thousands of hard crab trips per year taken from the LDWF Trip Ticket Program.

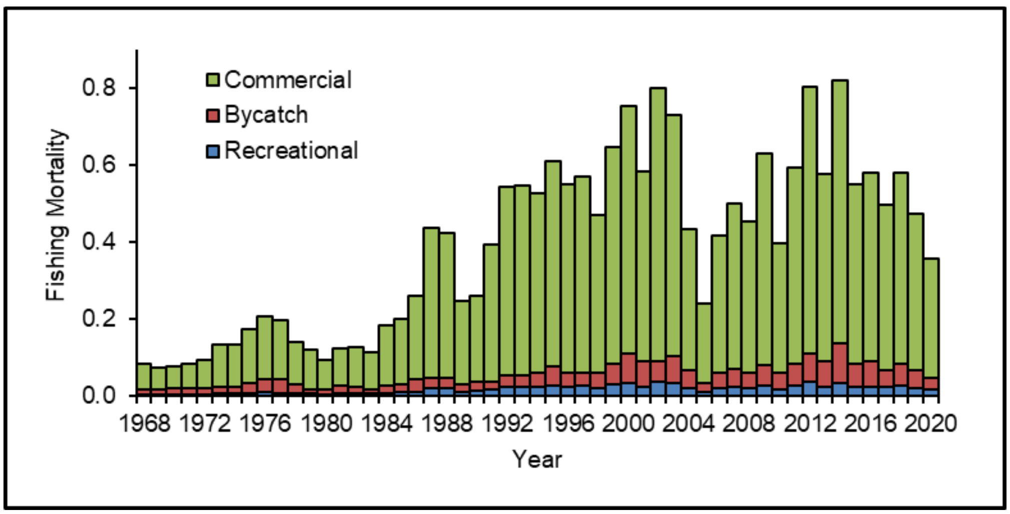


Figure 9: Fleet-specific (commercial, recreational, and dead bycatch) fishing mortality estimated from the catch-survey model.

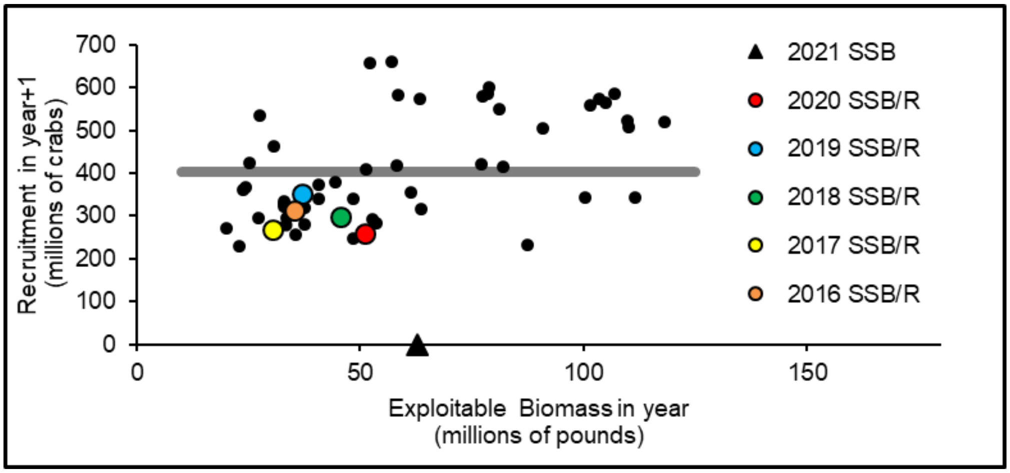


Figure 10: Exploitable biomass and subsequent recruitment of Louisiana blue crab *Callinectes sapidus*. Estimates are derived from the catch-survey model. Recruits (juveniles) are crabs ≥25mm and <125mm carapace width. Adult crabs are ≥125mm carapace width. Abundance units are millions of individuals. Biomass units are millions of pounds. The 5 most recent data pairs and the 2021 exploitable biomass estimate are identified.

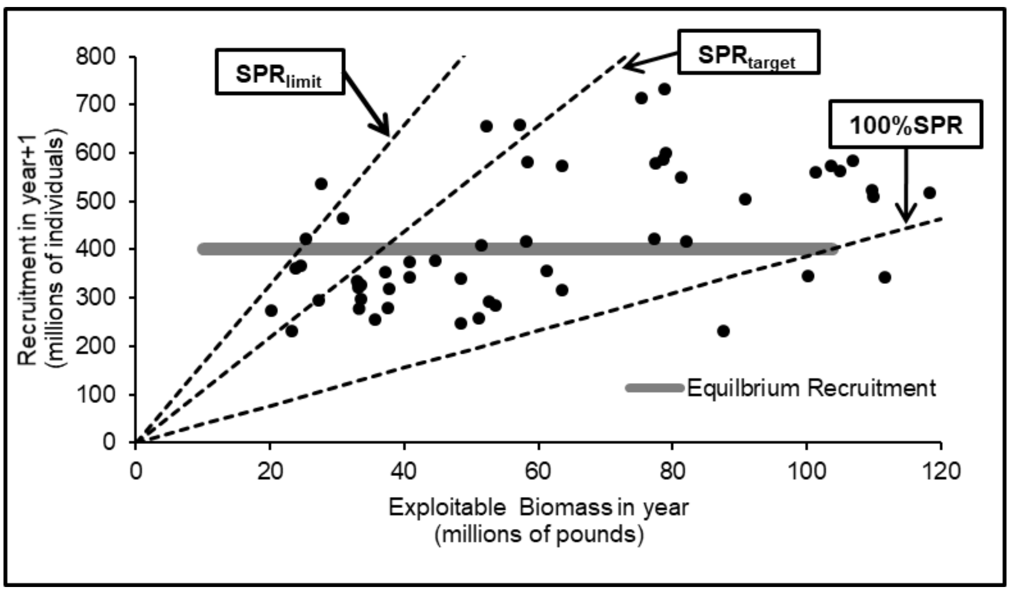


Figure 11: Equilibrium recruitment and the fished and unfished estimates of recruitment per spawner (represented by the slopes of the diagonal lines) corresponding with 23.6, 35.4, and 100% SPR. Exploitable biomass and recruitment of Louisiana blue crab *Callinectes sapidus* are derived from the catch-survey model. Recruits (juveniles) are crabs ≥25mm and <125mm carapace width. Adult (exploitable) crabs are ≥125mm carapace width. Abundance units are millions of individuals. Biomass units are millions of pounds.

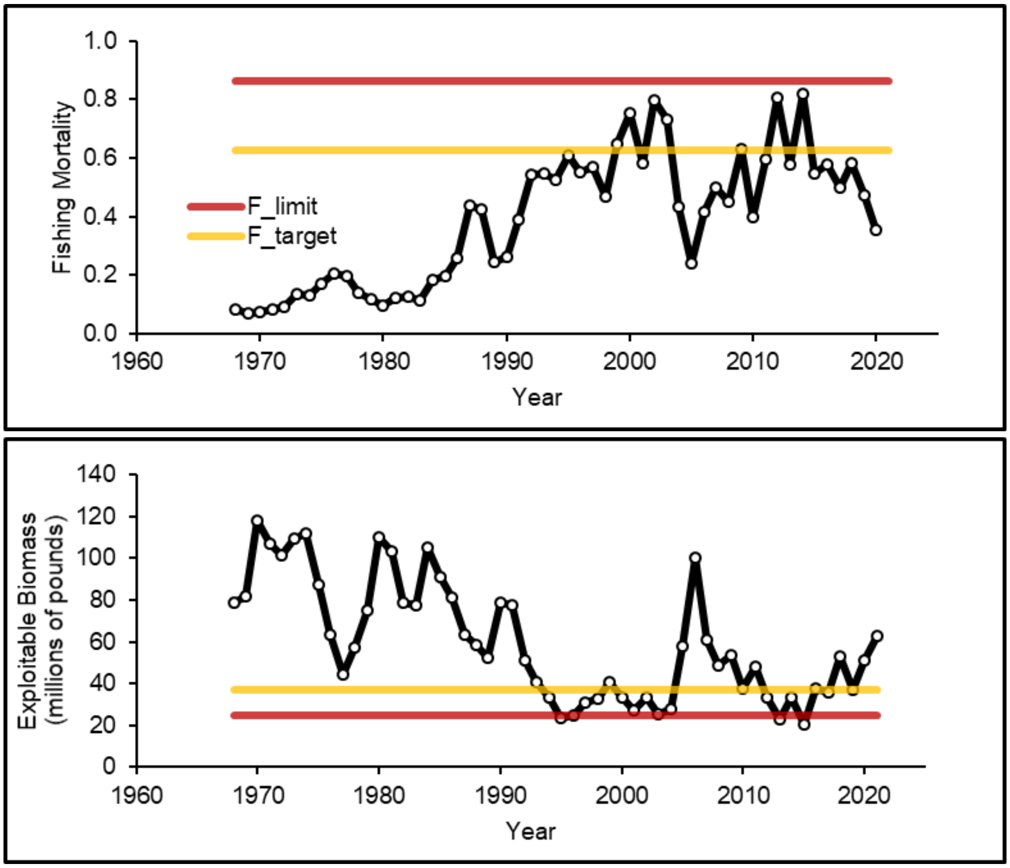


Figure 12: Time-series of catch-survey model fishing mortality rates and exploitable biomass estimates relative to management benchmarks.

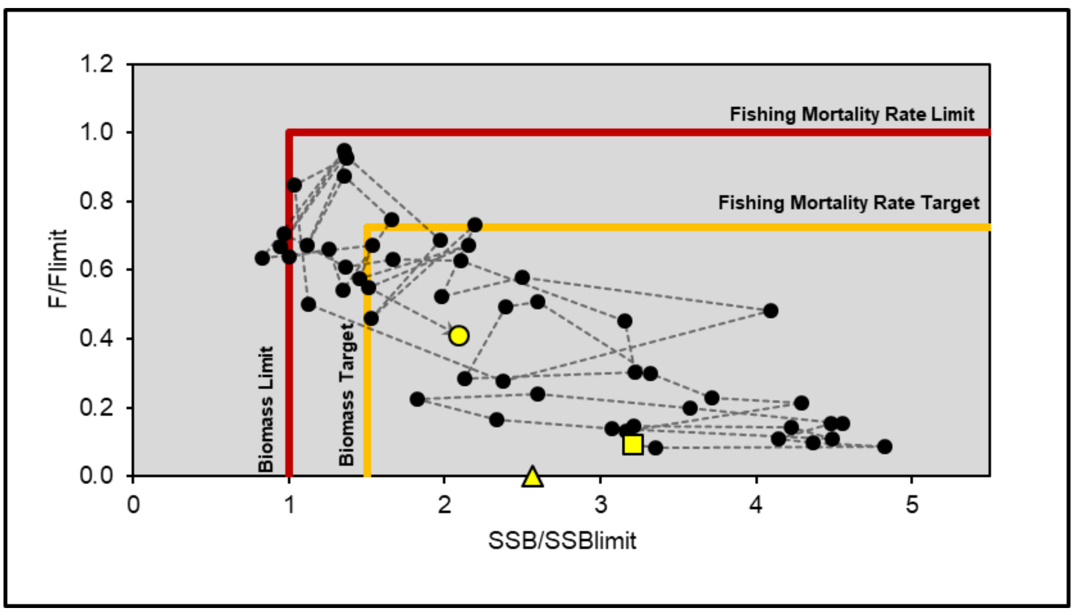


Figure 13: Ratios of annual fishing mortality rates and exploitable biomass estimates to F_{limit} and SSB_{limit}. Exploitable biomass and instantaneous fishing mortality are estimated from the catch-survey model. The biomass limit and target are represented by the solid vertical lines. The fishing mortality rate limit and target are represented by the solid horizontal lines. The square represents the first year of data pairs and the circle represents the last. The triangle represents the 2021 exploitable biomass estimate.

Appendix 1:

JOHN BEL EDWARDS
GOVERNOR

JACK MONTOUCET
SECRETARY

Evaluation of Commercial Shrimp Fishery Bycatch in Louisiana Waters

Peyton Cagle and Joe West
Office of Fisheries
Louisiana Department of Wildlife and Fisheries
November 2020

Overview

Project Need

In 2010, a Fisheries Improvement Project (FIP) was initiated for the commercial shrimp fishery operating in Louisiana (LA) waters as a first step in the process of achieving a sustainability certification for the fishery. This was followed by an official improvement plan for the fishery in 2012. By 2015, the LA shrimp fishery met the goals outlined in the initial plan which allowed the fishery to progress into a comprehensive FIP that addresses all issues within the fishery to ensure the fishery is in compliance with the sustainability standards outlined by the certifying body.

Several action items were outlined in the comprehensive FIP, including the need for current bycatch data from the fishery to assess the main bycatch species per standards of the certifying body. The Louisiana Shrimp Task Force (LSTF) and involved members of the industry approached the Louisiana Department of Wildlife and Fisheries (LDWF) in 2016 and initiated discussions to conduct a study to characterize the current bycatch of the fishery in LA waters. In 2018, LDWF partnered with the LSTF and the American Shrimp Processors Association (ASPA) to fund a one-year observer study designed by the LDWF to focus exclusively on the bycatch of the shrimp fishery operating in LA waters, as the bycatch of the fishery operating in federal waters is monitored and reported by NOAA Fisheries.

Project Objectives

Objectives of this study were:

1. Characterize the current bycatch of the commercial shrimp fishery operating in LA waters.
2. Identify the main bycatch species of the fishery per standards of the Audubon Nature Institute (ANI) Gulf United for Lasting Fisheries (GULF) Responsible Fisheries Management (RFM) program (ANI 2020).
3. Assess the population resilience of the main bycatch species to fisheries exploitation.

Fishery Description

The commercial harvest of shrimp in LA dates back to the 1800s (LDWF 2016). As the popularity of shrimp as a food source grew in the early 1900s, the LA commercial shrimp industry expanded and commercial landings began to increase above 20 million pounds annually. Continued expansion of the industry into current times has led to the most valuable commercial fishery operating in LA waters with landings averaging over 70 million pounds annually in the most recent decade.

In the early 1900s, the otter trawl was developed and became the primary fishing gear used by LA shrimp fishers. This was followed by introduction of the butterfly net in the 1950s that allowed stationary fishing in tidal passes. The introduction of skimmer nets in the 1980s, which allowed fishers to focus efforts in shallower water and fish the entire water column, was widely accepted by the LA shrimp fishery.

A shift in gear preference of the LA commercial shrimp fishery has occurred over time as well as an overall decrease in license sales (Table 1). Based on commercial gear license sales, the use of otter trawl and butterfly net gear has decreased since 2000 while the use of skimmer nets has increased. The overall number of commercial licenses sold has decreased by over 70% since 2000.

Commercial shrimp landings in LA waters and the corresponding number of fishery trips have also decreased since 2000 (Figure 1). Commercial landings have decreased over 30% since 2000 while the number of fishery trips has declined by over 65%. This disproportionate decrease is primarily due to the characteristics of the shrimp fishery operating in LA waters changing over time, where a noticeable decline occurred in the mid-2000’s in the number of trips less than 1-day at sea.

Regulatory Authority

Regulatory authorities for the LA shrimp fishery are the Governor of Louisiana, the Louisiana Legislature, the Louisiana Wildlife and Fisheries Commission (LWFC), and the Secretary of LDWF. The Governor has the authority to issue executive orders, in limited instances, which are enforced in the same manner as statutes passed by the legislature. The LA Legislature has the authority to enact laws to protect, conserve, and replenish the natural resources of the state, such as gear regulations, licensing requirements, and entry limitations. Some of the authority of the legislature has been delegated to the LWFC, allowing regulatory authority of seasons, quotas, size limits, and possession limits.

Specific to commercial shrimping, the LWFC has the authority to open and close state outside waters, set the inshore shrimp season dates, and modify gear mesh sizes during the special shrimp seasons. The LWFC also has the authority to promulgate regulations regarding the use and configuration of excluder devices. Some authority of the LWFC is delegated to the Secretary of LDWF, including the ability to open or close special and regular shrimp seasons as well as open or close state outside waters.

Methods

Bycatch Characterization

In 2019, LDWF, along with the LSTF and ASPA, initiated an observer study of the commercial shrimp fishery operating in Louisiana waters to characterize bycatch of the fishery from July 2019 through June

2020. LGL Ecological Research Associates, Inc. (LGL) was contracted for this study to provide biological staff to act as observers onboard commercial shrimp fishing vessels operating in LA waters.

Fishery participants were solicited though the LSTF, social media, and LDWF news releases, and an online portal was developed for interested commercial fishers to enroll. All commercial fishers operating out of LA ports were eligible to participate in this study. Commercial vessels in which observers were placed were selected randomly from the pool of participating commercial fishers. Commercial fishers randomly drawn from this group were compensated $350 per day for each fishing trip where bycatch was observed by an LGL biologist. Fishing trips conducted with observers onboard were not to exceed 48 hours. Trips in which observers were placed were randomly assigned proportional to the recent fishery effort (number of trips) by fishing gear, LDWF Coastal Study Area (CSA), and fishing season (spring, fall, inshore closed).

Bycatch information was collected over the duration of each observed trip by sampling each tow. On vessels containing multiple nets, samples were collected by alternating which net the samples were collected from after each tow. Any observed interactions with sea turtles were to be documented, regardless of which net was sampled.

For each net sampled, the total weight of the tow was estimated through a volumetric approach as described in the NOAA Observer Training Manual (NOAA Fisheries 2010). Multiple fish baskets were equally filled with the entire catch of the sampled tow and then one fish basket was randomly chosen, weighed and used to extrapolate the weight of the entire tow's catch from the number of baskets filled. Catch of the randomly chosen basket was also characterized by sorting, enumerating, and weighing each species to the nearest gram with the exception of white and brown shrimp and jellyfish species where only weight measurements were recorded. The species weight composition of the subsample was then used to extrapolate the total catch weight of each tow.

Size measurements of up to thirty individuals per sampled tow were recorded for penaeid shrimp species and other selected species that are managed or commonly harvested. Large specimens that weren't included in the volumetric sampling method were identified by species, counted, released condition documented, and size or weight measurements recorded when possible. Tow times and locations were also recorded along with the position of the sampled net for each tow.

Main Bycatch Identification

The ANI GULF RFM program identifies relevant bycatch (non-target catches), whether discarded or retained, as managed non-target species (species regulated for commercial, bait, or recreational use) greater than 1% of total catch and non-managed non-target species greater than 10% of total catch (ANI 2020).

Resilience to Exploitation

Population resilience is a population's ability to withstand perturbation. Populations with higher resilience are at less risk of extinction due to fishery exploitation than populations with lower resilience. Productivity, which is a function of growth rates, fecundity, natural mortality, age at maturity, and longevity, can be a reasonable proxy for population resilience. Productivity classification indices were developed for each species identified as main bycatch from their life history characteristics based on a classification scheme developed at the Food and Agricultural Organization of the United Nations (FAO) second technical consultation on the suitability of the Convention on International Trade in Endangered Species (CITES) criteria for listing commercially-exploited aquatic species (FAO 2001).

Results

Bycatch Characterization

Thirty-three shrimp fishing trips with 363 tows and 501 hours of tow time were observed from July 2019 through June 2020 from 12 individual commercial fishing vessels. Of the twelve participating vessels, 9 fished with skimmer nets, 2 with otter trawls, and 1 with butterfly net gear. The otter trawls were all equipped with bycatch reduction devices (BRDs) and turtle excluder devices, and two-thirds of the skimmer nets were equipped with BRDs.

Observer coverage of the fishery over the course of this study was approximately 0.1% (33 observed trips/37,203 fishery trips) and nearly proportional to the number of fishery trips by gear, CSA, and fishing season with the exception of CSA 6 and 7 due to the lack of fishery participation in those areas (Table 2, Figure 2).

From the 363 observed tows, 14,266 kg of total catch was observed consisting of 105 unique species or grouped species (Table 3). Four species of penaeid shrimp, 82 finfish species, 12 crustacean species (excluding penaeid shrimp), and 7 non-crustacean invertebrate species were observed. Penaeid shrimp species were the highest group caught by weight (48.1%), followed by finfish (40.2%), crustaceans other than penaeid shrimp (5.0%), and invertebrates (3.0%). Debris made up 3.7% of the total catch by weight.

The most abundant species caught consisting of >1% by weight of the total catch were white shrimp (44.3%), Gulf menhaden, (14.1%), Atlantic croaker (5.4%), blue crab (4.9%), brown shrimp (3.7%), spot (3.2%), jellyfish sp. (2.9%), sand seatrout (2.8%), hardhead catfish (2.2%), gafftopsail catfish (2.1%), and Atlantic cutlassfish (2.1%).

The bycatch to shrimp sample ratio error distribution was assumed lognormal and the corresponding sample ratio geometric mean in units of weight was 1.01 (Table 4). Size compositions and mean sizes of penaeid shrimp and the managed and commonly harvested species catches are presented in Table 5. Catch composition of large specimens not represented in the volumetric samples are presented in Table 6 along with released condition and corresponding size and weight measurements if available. Interactions with diamondback terrapins were observed in which all were released alive (Table 6). No interactions with sea turtles were observed.

Main Bycatch Identification

Gulf menhaden and blue crab were identified as the main bycatch species of the current LA commercial shrimp fishery per ANI standards. Both are managed species that are greater than 1% of the total catch by weight. The other non-target species consisting of greater than 1% of the total catch are non-managed species not regulated for recreational, bait, or commercial use. No non-managed non-target species was greater than 10% of the total catch by weight.

Resilience to Exploitation

Blue crab and Gulf menhaden were assigned productivity/resilience levels (high, medium, or low) based on each species life history characteristics (Table 7). Life history parameter values were taken from the most recent stock assessments if available (SEDAR 2018, West et al. 2019). Parameter values not available in the stock assessment reports were taken from FishBase (Froese and Pauly 2011) and SeaLifeBase (Palomares and Pauly 2020). Parameter values for each of the main bycatch species indicate overall high productivity/resilience.

Discussion

Historic Bycatch Ratios

The bycatch to penaeid shrimp sample ratio mean from this study (1.01) is less than an earlier LDWF shrimp bycatch study conducted in LA waters (Adkins 1993). The bycatch to penaeid shrimp sample ratio mean in that study, recalculated as a geometric mean, was 1.24, suggesting bycatch in the LA shrimp fishery has decreased through time. This decrease is likely due to the changing characteristics of the fishery where skimmer nets have become the preferred gear of the fishery, along with the use of BRDs. An earlier NOAA Fisheries bycatch study conducted in LA waters (Scott-Denton et al. 2006), which only characterized bycatch from the skimmer net fishery operating primarily in Vermilion Bay (CSA 6), reported an overall ratio of bycatch to penaeid shrimp of 0.63.

Management Implications

For managed species identified as main bycatch, the ANI standards require the effects of the fishery to be considered. Consideration of managed non-target species aims primarily at establishing whether the overall effects of fishing on the stock under consideration and all significant removals are accounted for; and that the management strategy and relative measures are effective in maintaining other managed species from experiencing overfishing and other impacts that are likely to be irreversible or very slowly reversible (ANI 2020).

The main bycatch species of the LA commercial shrimp fishery per ANI standards (Gulf menhaden and blue crab) are regulated species which undergo periodic stock assessments that output estimates used as metrics of stock status (SEDAR 2018, West et al. 2019) with fisheries that currently hold Global Sustainable Seafood Initiative (GSSI) accredited sustainability certifications. Removals of Gulf menhaden and blue crab as bycatch from the LA shrimp fishery have not been considered in the respective stock assessments. Bycatch from the offshore Gulf of Mexico shrimp fishery was considered in the most recent Gulf menhaden stock assessment (SEDAR 2018), but was ultimately not used as a model input by the assessment panelists due to the high uncertainty in the estimated time-series and the relatively insignificant level of bycatch when compared to the landings of the fishery.

Future LDWF blue crab and SEDAR Gulf menhaden stock assessments would be required to consider removals from the LA shrimp fishery per ANI standards. Time-series of bycatch removals could be estimated directly from annual LA shrimp landings from the mean bycatch to shrimp ratio from this study and the earlier LDWF study (Adkins 1993) along with the percent composition of blue crab and Gulf menhaden in the catches and assumptions of discard mortality. These time-series would unfortunately be considered highly uncertain due to the few bycatch to shrimp ratio estimates available in LA waters over time coupled with the changing characteristics of the fishery, but would allow accurate estimation of the current bycatch removals of the LA shrimp fishery to determine their significance relative to the directed landings of each fishery.

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<u>Tables</u>

Table 1. Louisiana annual commercial shrimp gear license sales (percent by gear and total sales), 2000-2019.

Year	Trawl	Skimmer	Butterfly	Total
2000	54%	34%	12%	22,218
2001	52%	37%	10%	22,865
2002	51%	40%	9%	21,627
2003	48%	44%	8%	20,586
2004	48%	43%	8%	17,347
2005	46%	45%	9%	15,420
2006	44%	48%	9%	13,646
2007	43%	48%	9%	12,590
2008	42%	49%	10%	11,476
2009	40%	50%	10%	12,082
2010	38%	52%	10%	12,806
2011	37%	54%	9%	13,234
2012	38%	53%	8%	12,728
2013	29%	64%	7%	10,123
2014	42%	49%	9%	7,319
2015	41%	50%	9%	7,551
2016	41%	51%	9%	7,340
2017	41%	51%	8%	6,867
2018	41%	51%	8%	6,236
2019	40%	51%	8%	5,791

Table 2: Louisiana shrimp fishery trips and observer coverage (July 2019 – June 2020) by gear, CSA, and fishing season.

Fishery trips	37,203
Observed trips	33

	Fishery trips		Observed trips	
Gear	Frequency	Percent	Frequency	Percent
Butterfly net	2276	6.1%	3	9.1%
Otter trawl	6452	17.3%	6	18.2%
Skimmer net	28475	76.5%	24	72.7%

	Fishery trips		Observed trips	
CSA	Frequency	Percent	Frequency	Percent
1	6564	17.6%	7	21.2%
3	11136	29.9%	12	36.4%
5	14607	39.3%	14	42.4%
6	1108	3.0%	0	0.0%
7	3788	10.2%	0	0.0%

	Fishery trips		Observed trips	
Season	Frequency	Percent	Frequency	Percent
Spring	7823	21.0%	7	21.2%
Fall	24457	65.7%	24	72.7%
Inshore closed	4923	13.2%	2	6.1%

Table 3: Species total catch composition and corresponding mean weights. Species mean weights are calculated from the subsampled weights and counts.

Species	total kg	% kg	mean kg
WHITE SHRIMP	6321.765	44.313	--
GULF MENHADEN	2013.137	14.111	0.014
ATLANTIC CROAKER	768.736	5.389	0.011
BLUE CRAB	700.646	4.911	0.054
BROWN SHRIMP	527.423	3.697	--
DEBRIS	521.480	3.655	--
SPOT	449.081	3.148	0.030
JELLYFISH SP.	415.590	2.913	--
SAND SEATROUT	402.123	2.819	0.012
HARDHEAD CATFISH	314.820	2.207	0.018
GAFFTOPSAIL CATFISH	302.624	2.121	0.015
ATLANTIC CUTLASSFISH	299.163	2.097	0.021
ATLANTIC THREAD HERRING	117.899	0.826	0.015
BAY ANCHOVY	102.212	0.716	0.001
GIZZARD SHAD	94.846	0.665	0.019
THREADFIN SHAD	68.982	0.484	0.014
COWNOSE RAY	68.401	0.479	0.772
SPANISH MACKEREL	67.702	0.475	0.023
SPOTTED SEATROUT	66.077	0.463	0.080
ATLANTIC MOONFISH	62.295	0.437	0.008
CATFISH SP.	54.260	0.380	0.022
STRIPED MULLET	43.462	0.305	0.039
ATLANTIC STINGRAY	41.300	0.289	0.215
HARVESTFISH	36.490	0.256	0.025
PINFISH	31.478	0.221	0.039
STRIPED ANCHOVY	31.222	0.219	0.012
HOGCHOKER	25.958	0.182	0.016
SHEEPSHEAD	23.683	0.166	1.203
SOUTHERN FLOUNDER	23.201	0.163	0.337
SOUTHERN KINGFISH	20.237	0.142	0.032
SILVER PERCH	17.558	0.123	0.026
SEABOB	17.386	0.122	0.005
BLUE CATFISH	16.445	0.115	0.007
LEAST PUFFER	16.150	0.113	0.007
WHITE MULLET	16.042	0.112	0.023
ATLANTIC BRIEF SQUID	15.726	0.110	0.009
BAY WHIFF	15.136	0.106	0.009
SCALED SARDINE	14.126	0.099	0.007
LADYFISH	10.005	0.070	0.102
CREVALLE JACK	9.887	0.069	0.028
STAR DRUM	8.882	0.062	0.014
INSHORE LIZARDFISH	8.292	0.058	0.034
ATLANTIC SPADEFISH	7.770	0.054	0.013
HIGHFIN GOBY	7.558	0.053	0.027
ATLANTIC BUMPER	6.027	0.042	0.003
VIOLET GOBY	5.584	0.039	0.030
LOOKDOWN	4.889	0.034	0.015
FLORIDA POMPANO	4.535	0.032	0.092
BLUE RUNNER	4.382	0.031	0.045
BLACK DRUM	3.471	0.024	0.088
GRAY SNAPPER	3.053	0.021	0.044
HERMIT CRAB SP.	2.905	0.020	0.018

Table 3 (continued):

Species	total kg	% kg	mean kg
BANDED DRUM	2.866	0.020	0.006
ATLANTIC MIDSHIPMAN	2.304	0.016	0.022
GULF STONE CRAB	2.166	0.015	0.440
ATLANTIC NEEDLEFISH	2.048	0.014	0.026
BLACKTIP SHARK	1.970	0.014	0.200
ATLANTIC SILVERSTRIPE HALFBEAK	1.871	0.013	0.035
SPINY SEAROBIN	1.723	0.012	0.004
LEATHERJACKET	1.615	0.011	0.008
INLAND SILVERSIDE	1.600	0.011	0.004
BIGHEAD SEAROBIN	1.590	0.011	0.005
ROUGH SILVERSIDE	1.492	0.010	0.002
BLACKCHEEK TONGUEFISH	0.985	0.007	0.033
GULF TOADFISH	0.886	0.006	0.036
PIGFISH	0.886	0.006	0.060
STRIPED BURRFISH	0.886	0.006	0.180
GULF BUTTERFISH	0.768	0.005	0.005
NEEDLEFISH SP.	0.704	0.005	0.029
SNAIL SP.	0.689	0.005	0.016
NAKED SOLE	0.596	0.004	0.020
NORTHERN KINGFISH	0.596	0.004	0.040
SHARKSUCKER	0.566	0.004	0.038
ISOPODA SP.	0.502	0.004	0.034
BAYOU KILLIFISH	0.478	0.003	0.019
GIANT TIGER PRAWN	0.359	0.003	0.073
FALSE SILVERSTRIPE HALFBEAK	0.355	0.002	0.024
ATLANTIC MENHADEN	0.345	0.002	0.070
MOJARRA SP.	0.295	0.002	0.015
BLUNTNOSE JACK	0.251	0.002	0.009
FALSE SHARK EYE	0.246	0.002	0.013
CRESTED CUSK EEL	0.197	0.001	0.040
THINSTRIPE HERMIT CRAB	0.197	0.001	0.013
FAT SLEEPER	0.177	0.001	0.018
FRINGED FLOUNDER	0.158	0.001	0.004
FLORIDA ROCKSNAIL	0.148	0.001	0.015
OYSTER TOADFISH	0.148	0.001	0.030
RIVER SHRIMP	0.148	0.001	0.030
SPOTFIN MOJARRA	0.148	0.001	0.015
YELLOWFIN MOJARRA	0.148	0.001	0.008
PYGMY SEA BASS	0.108	0.001	0.022
SMOOTH PUFFER	0.103	0.001	0.011
AMERICAN PADDLEFISH	0.098	0.001	0.020
BIVALVE CLAM SP.	0.098	0.001	0.020
MANTIS SHRIMP	0.098	0.001	0.010
PINK PURSE CRAB	0.098	0.001	0.010
WHITE RIVER CRAWFISH	0.098	0.001	0.010
SILVER ANCHOVY	0.079	0.001	0.008
BIGCLAW SNAPPING SHRIMP	0.049	0.000	0.010
REDEAR SUNFISH	0.049	0.000	0.010
FLORIDA LADY CRAB	0.044	0.000	0.009
TIDEWATER MOJARRA	0.044	0.000	0.009
ESTUARINE MUD CRAB	0.015	0.000	0.001
BIGEYE ROBIN	0.005	0.000	0.001
GULF PIPEFISH	0.005	0.000	0.001
SPECKLED SWIMMING CRAB	0.005	0.000	0.001

Table 4: Bycatch to penaeid shrimp (brown, white, seabob) sample ratio summary statistics in units of weight. The sample ratio mean and error estimates are geometric.

Ratio (bycatch /shrimp)		
Bin	Frequency	Percent
0.0	163	50.309
1.0	55	16.975
2.0	39	12.037
3.0	18	5.556
4.0	16	4.938
5.0	12	3.704
6.0	5	1.543
7.0	4	1.235
8.0	2	0.617
9.0	--	--
10.0	2	0.617
11.0	--	--
12.0	--	--
13.0	1	0.309
14.0	--	--
15.0	1	0.309
16.0	2	0.617
17.0	--	--
18.0	--	--
19.0	2	0.617
--	--	--
51.0	1	0.309
--	--	--
111.0	1	0.309

Ratio (bycatch/shrimp)	
Mean	1.013
L95%CI	0.882
U95%CI	1.163
CV	1.986
Tows	324

Table 5: Bycatch size compositions of managed and commonly harvested species. Size measurements are fork length (finfish), total length (shrimp), and carapace width (crab).

Size bin (cm)	ATLANTIC CROAKER	BLACK DRUM	BLUE CRAB	BROWN SHRIMP	GRAY SNAPPER	GULF MENHADEN	SEABOB	SHEEPSHEAD	SOUTHERN FLOUNDER	SPOTTED SEATROUT	STRIPED MULLET	WHITE SHRIMP
0	2	--	--	--	--	--	--	--	--	--	--	--
1	1	--	30	1	--	--	--	--	--	--	--	--
2	--	--	96	1	2	1	--	--	--	--	--	1
3	3	--	291	--	1	6	--	--	--	--	--	6
4	1	--	358	15	--	64	--	--	--	--	--	14
5	39	--	285	91	--	302	--	--	--	--	--	74
6	284	--	177	419	--	627	1	--	--	--	1	263
7	485	--	139	1,087	--	1,074	6	--	--	--	2	700
8	748	1	111	1,246	--	970	28	--	--	--	4	1,039
9	632	--	91	635	--	579	34	--	--	5	9	1,043
10	618	--	94	260	1	742	15	--	--	9	24	788
11	988	--	123	112	1	830	1	--	--	12	39	1,035
12	822	--	116	20	--	330	--	--	--	18	25	1,395
13	513	--	89	4	1	156	--	--	--	11	30	1,562
14	261	--	82	1	--	172	--	--	--	6	27	1,021
15	120	--	99	--	--	126	--	--	--	6	16	336
16	55	--	124	--	--	53	--	--	--	6	12	78
17	24	2	71	--	--	11	--	--	--	8	6	9
18	10	--	24	1	--	5	--	--	--	1	8	2
19	3	3	6	--	--	1	--	--	--	4	6	2
20	1	1	--	--	--	1	--	--	1	8	3	--
21	3	1	--	--	--	--	--	--	1	12	2	--
22	--	--	--	--	--	1	--	--	--	13	1	--
23	--	--	--	--	--	--	--	--	1	5	2	--
24	--	--	--	--	--	--	--	--	1	6	--	--
25	--	--	--	--	--	--	--	--	--	8	--	--
26	--	--	--	--	--	--	--	--	1	3	--	--
27	--	--	--	--	--	--	--	--	--	5	--	--
28	--	--	--	--	--	--	--	--	1	4	--	--
29	--	--	--	--	--	--	--	--	1	2	--	--
30	--	--	--	--	--	--	--	1	1	2	--	--
31	--	--	--	--	--	--	--	--	--	--	--	--
32	--	--	--	--	--	--	--	1	--	--	--	--
33	--	--	--	--	--	--	--	--	--	2	--	--
34	--	--	--	--	--	--	--	1	--	3	--	--
35	--	--	--	--	--	--	--	--	2	--	--	--
36	--	--	--	--	--	--	--	--	1	1	--	--
37	--	--	--	--	--	--	--	--	1	--	--	--
38	--	--	--	--	--	--	--	--	--	--	--	--
39	--	--	--	--	--	--	--	--	--	--	--	--
40	--	--	--	--	--	--	--	--	--	--	--	--
41	--	--	--	--	--	--	--	--	--	--	--	--
42	--	--	--	--	--	--	--	--	--	--	--	--
43	--	--	--	--	--	--	--	1	--	--	--	--
Mean size (mm)	107	176	83	82	73	94	91	354	290	187	135	113
n	5613	8	2406	3893	6	6051	85	4	12	160	217	9368

Table 6: Large specimen catch composition. Size measurements are fork length.

		released condition			weight (kg)				size (mm)			
Species	numbers	alive	dead	unknown	mean	n	min	max	mean	n	min	max
Black Drum	33	20	2	11	7.67	2	6.98	8.35	905	1	905	905
Cownose Ray	27	5	--	22	0.81	5	0.60	0.96	323	4	136	410
Atlantic Stingray	25	10	11	4	0.86	3	0.41	1.16	146	1	146	146
Sheepshead	15	10	1	4	2.59	3	2.48	2.78	494	3	460	528
Longnose Gar	12	12	--	--	--	--	--	--	--	--	--	--
Diamondback Terrapin	5	5	--	--	--	--	--	--	--	--	--	--
Red Drum	5	5	--	--	--	--	--	--	--	--	--	--
Hardhead Catfish	5	5	--	--	--	--	--	--	--	--	--	--
Alligator Gar	4	4	--	--	--	--	--	--	1140	2	450	1829
Atlantic Tripletail	3	2	--	1	--	--	--	--	--	--	--	--
Bull shark	2	2	--	--	4.92	2	4.83	5.01	--	--	--	--
Spotted Seatrout	2	2	--	--	--	--	--	--	--	--	--	--
Bonnethead	1	1	--	--	--	--	--		--	--	--	--
Blacktip Shark	1	1	--	--	3.62	1	3.62	3.62	566	1	566	566

Table 7: FAO proposed guideline for indices of productivity/resilience for exploited aquatic species (top table) and corresponding productivity/resilience levels for blue crab and Gulf menhaden (bottom table). Parameter values are taken from the latest stock assessment reports (West et al. 2019, SEDAR 63) unless noted by an * where values are taken from FishBase (Froese and Pauly 2011) for Gulf menhaden and SeaLifeBase (Palomares and Pauly 2020) for blue crab.

	Productivity/Resilience		
Parameter	Low	Medium	High
Intrinsic rate of population growth (r per yr)	<0.14	0.14 - 0.35	>0.35
Natural mortality rate (M per yr)	<0.2	0.2 - 0.5	>0.5
Individual growth rate (K per yr)	<0.15	0.15 - 0.33	>0.33
Age at maturity (yrs)	>8	8 - 3.3	<3.3
Maximum age (yrs)	>25	14 - 25	<14
Generation time (yrs)	>10	10.0 - 5.0	<5

	Blue Crab		Gulf Menhaden	
Parameter	Value	Index	Value	Index
Intrinsic rate of population growth (r per yr)	0.6*	High	3.0*	High
Natural mortality rate (M per yr)	1.0	High	1.1	High
Individual growth rate (K per yr)	1.9	High	0.3	High
Age at maturity (yrs)	1.0	High	2.0	High
Maximum age (yrs)	3.0	High	6.0	High
Generation time (yrs)	<3.0	High	2.4*	High
Overall productivity /resilience level	High		High	

Figures

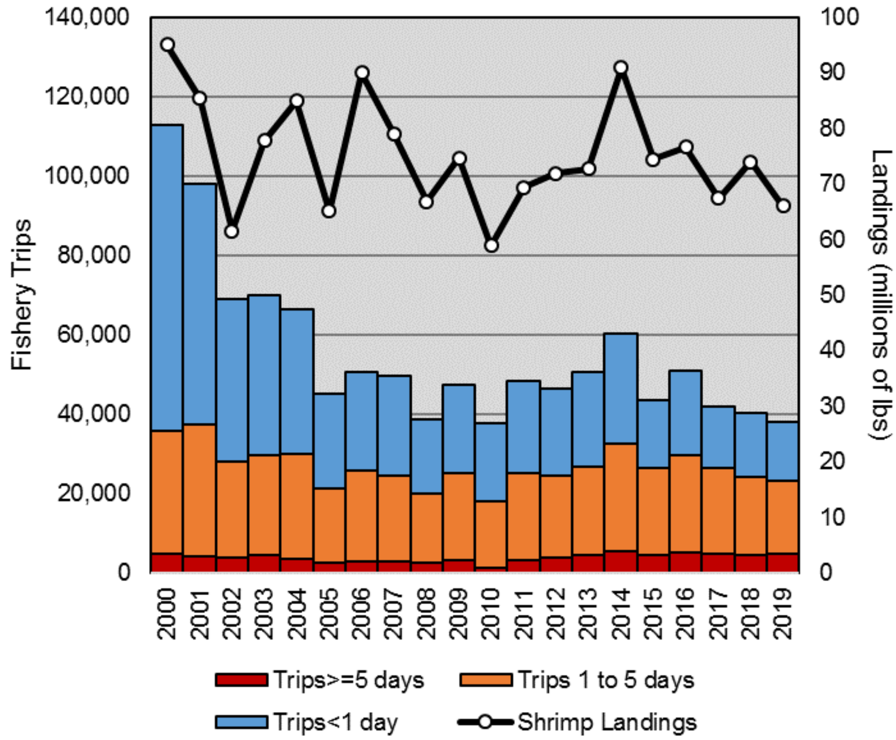

Figure 1: Shrimp fishery trips in LA waters by number of days at sea and corresponding total penaeid shrimp landings taken from the LDWF Trip Ticket program, 2000-2019. Note: Landings and fishery trips do not include records from out of state or federal waters.

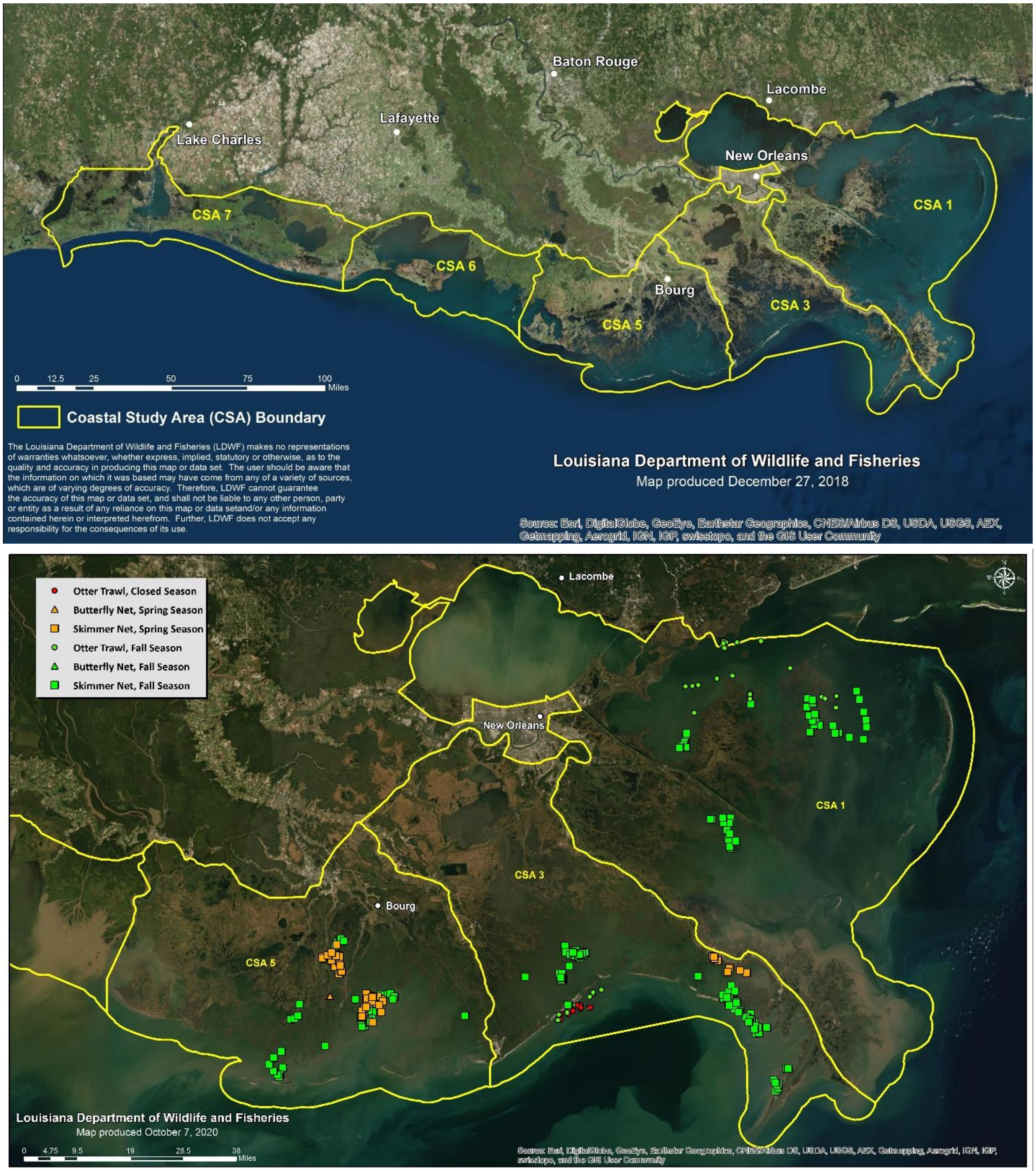

Figure 2: Louisiana state waters and LDWF Coastal Study Areas delineated by the yellow lines (top graphic) and locations of observed fishery tows (bottom graphic) by gear fished (otter trawl, skimmer net, butterfly net) and fishing season (spring, fall, inshore closed).